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HISTORICAL SUMMARY
LOKI ANTIAIRCRAFT FREE-FLIGHT
ROCKET SYSTEM
DECEMBER 1947 - NOVEMBER 1955

~~DECLASSIFIED BY 100-100-100~~
~~DATE 100-100-100~~

ORDNANCE CORPS • DEPARTMENT OF THE ARMY
REDSTONE ARSENAL
HUNTSVILLE, ALABAMA

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SPECIAL HISTORICAL MONOGRAPH
LOKI ANTIAIRCRAFT FREE-FLIGHT ROCKET
December 1947 - November 1955

U. S. ARMY ORDNANCE CORPS
REDSTONE ARSENAL
HUNTSVILLE, ALABAMA

Completed: 17 April 1957
Prepared By: Mary T. Cagle
Approved By: Brig General J. G. Shinkle

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PREFACE

This special historical monograph on the LOKI Antiaircraft Free-Flight Rocket System was compiled for the Office, Chief of Ordnance, in compliance with letter, ORDGX 00/TUO 4072, subject: "Historical Monograph on LOKI," dated 5 February 1957.

The material contained herein was furnished in draft form by Mr. Ernest K. Charlton, Chief of the Commodity Coordination Branch, Plans Coordination Office. According to Mr. Charlton, the material was written by the following technical personnel:

| <u>Name & Title</u> | <u>Subject of Material</u> |
|--|--|
| DR. CAROLD F. BJORK, Aeronautical Power Plant Dev Research Engineer, R&D Division-OML | R&D Program R&D Contract Cost |
| MR. RICHARD M. LEWIS Production Assistant, National Proc & Prod Br, Industrial Division | Industrial Program Industrial Contract Cost |
| MR. PAUL NEWMAN, Chief, Rocket Unit, Maint Sec, Ammo Br, Field Service Division | Field Service Program |

In connection with this history of the LOKI Rocket System, the reader's attention is invited to the special study entitled "Design, Development and Production of Rockets and Rocket Launchers," dated 1 July 1954, which was also prepared for the Office, Chief of Ordnance.

April 16, 1957

MARY T. CAGLE
Historian

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CHAPTER I

RESEARCH & DEVELOPMENT PROGRAM

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DEVELOPMENT OF PROGRAMS FROM INCEPTION THROUGH TERMINATION

In 1946 the War Department Equipment Board (Stilwell Board) began a review of the types of equipment required for the Army Ground Forces of the future. It was determined that the trend of developments of anti-aircraft targets would include partially armored aeroplanes flying at speeds sometimes exceeding that of sound and at heights from a few hundred feet to extremely high altitudes (Reference 1, Bibliog. I). Antiaircraft weapons available at that time lacked the flexibility, muzzle velocity and range necessary to discourage an invader utilizing these ultramodern aircraft (References 2 and 3, Bibliog. I).

During World War II, the Germans had done considerable work on the development of a liquid fueled free-flight antiaircraft rocket. It appeared that a weapon for engaging modern aircraft designed along these lines would cover the void between conventional antiaircraft guns and antiaircraft guided missiles. To promote this work Mr. Klaus Scheufelin, a German engineer who had been a key figure in development of the "TAIFUN" (as the German rocket was called), was brought to the United States in 1946 under Project Paperclip.

The TAIFUN was an unguided, liquid-propellant, antiaircraft rocket, development of which started at Peenemunde, Germany in 1944. Approximately 1,400 test rounds had been fired before the end of the war in Germany, and at that time performance was considered satisfactory. A mass production setup was ready for building enormous quantities of these missiles, but none had been manufactured when World War II ended.

With the assistance of three other German engineers at the Fort Bliss Rocket Sub-Office of the Ordnance Research & Development Division,

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Mr. Scheufelin prepared a feasibility study of a free-flight antiaircraft liquid fuel rocket and proposed a development program.

The characteristics of this weapon were informally discussed with Army Field Force Board No. 4, also at Fort Bliss, the members of which indicated their concurrence and desire for such a weapon. The plan was formalized under OCM Item 32030.

To meet the requirements cited above, the Department of the Army, in December 1947, approved initiation of the development of an antiaircraft free rocket weapon (Reference 4, Bibliog. I), to be named LOKI after the Norse God of Trouble and Mischief. The weapon was intended primarily for use at ranges up to 27,000 yards horizontal and 20,000 yards altitude against all types of aircraft traveling at speeds as great as 1,000 miles per hour. An accuracy of plus or minus 4 mils for 66% of the fired rounds was desired. The program also called for development of a suitable launcher and mount, high explosive head, fuze and fire control system.

Additional military characteristics called for a time of flight not to exceed 30 seconds to the maximum effective range. The fuze should not be susceptible to jamming devices and must not arm until the rocket was at least 100 yards from the launcher. The fuze was to destroy itself in cases where the intended target was not engaged. The fuels were to be packaged to permit storage over extended periods of time and at extremes of ambient temperatures. The launcher was to be light and of a multiple type capable of a load of at least 64 rockets. Complete launcher loading should be realized in less than 60 seconds. A trailed mount having weight, mobility and handling flexibility at least equal to that of the antiaircraft 90mm Gun Mount M2 was required. It should permit 6,400 mil uninterrupted

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traverse and elevation from zero to 1600 mils. The characteristics of the overall system included among other things:

1. Withstanding without damage severe transport and terrain conditions, including travel over both rough mountain and swamp roads; landings through surf and across beaches; glider landings; and air transport operations.
2. Spare parts, tools, and maintenance literature.

The specified minimum characteristics (Reference 4, Bibliog. I) of the missile included a field of fire not already covered by similar missiles. The warhead was to be designed to penetrate and destroy aircraft with a single hit.

The study cited above was used as a basis for discussions with possible development contractors, and the Eclipse-Pioneer Division of the Bendix Aviation Corporation was selected as the development contractor by OCO. The four German engineers were then made available to Bendix on a full-time basis to expedite the program.

Work done by the Bendix Corporation under Contract DA-30-069-ORD-4450 prior to 26 November 1948, is given in a Bendix report describing the status and objectives of the LOKI Program (Reference 5, Bibliog. I).

Feasibility Studies

The liquid propelled motor design and head design, as presented by Bendix in November 1948, are shown in Figure 1. The feasibility studies included designs of 245-pound and 24-pound liquid propelled missiles. The smaller missile was selected for development after consideration of the overall relative effort and expense required by a battery in order to bring down various sized aircraft, with a high degree of probability. It also seemed that the development of the smaller size missile would be less

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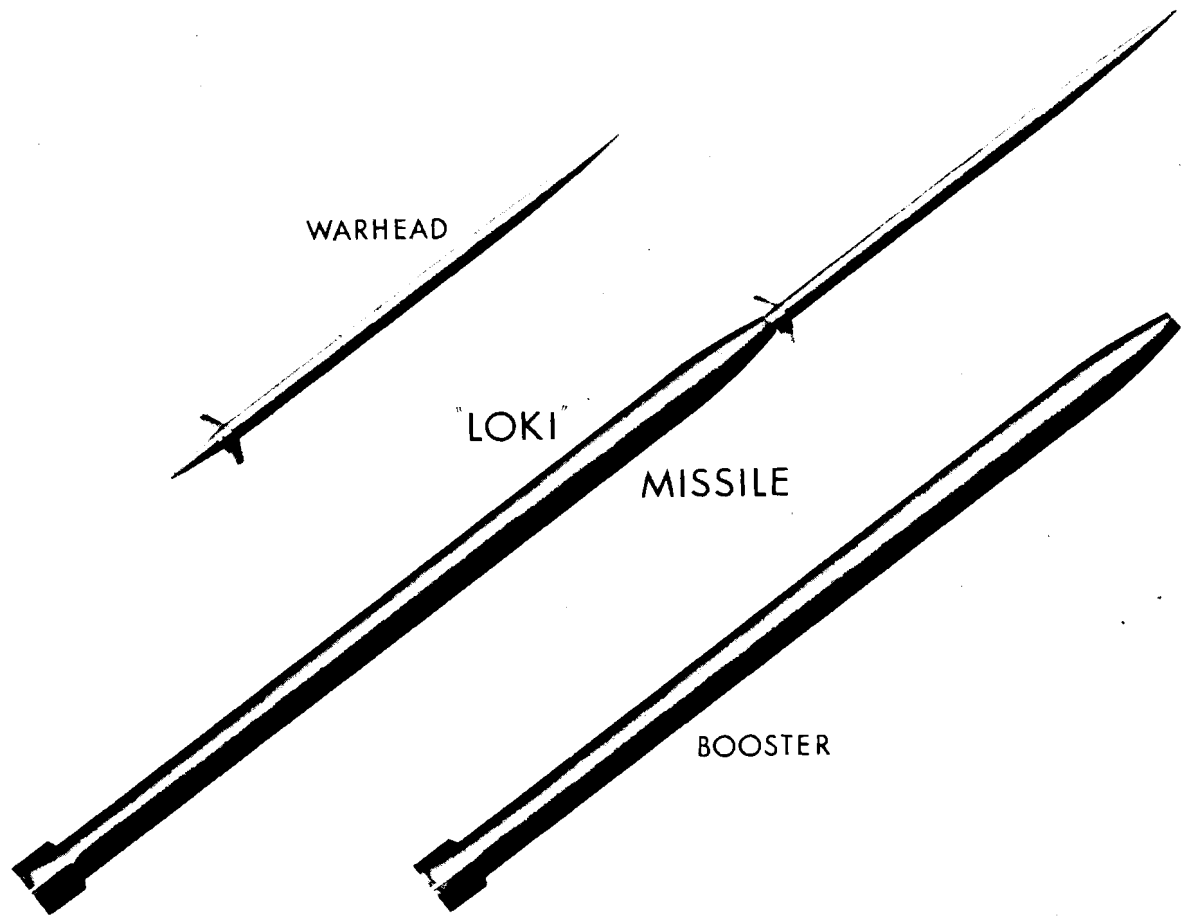


Figure 1

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expensive and require less time. It was pointed out that the smaller missile would cover a relatively untouched field in missile design. From Figure 1, it will be noticed that the booster and head are separable.

It was visualized that at the end of the boost phase the drag on the booster, being greater than that on the dart-like warhead, would promote separation. It was stated that the combination booster-warhead was unstable during the first period of propelled flight but would become stable during the second period, thereby minimizing the effect of sidewind on dispersion. Thrust malalignment was to be minimized by imparting a spin of about 17 revolutions per second to the missile. The propellant system selected was nitric acid-aniline. It was argued that nitric acid was chosen for the oxidizer because of the relative ease of storage compared to other oxidizers, plus the fact that it produced a high impulse per unit volume.

For pressurizing the propellants a solid fuel charge was proposed. It was ignited by black powder and a squib.

The nitric acid was to be loaded into the missile prior to shipment. The fuel was to be loaded into the missile in the field.

As indicated in the Bendix report (Reference 5, Bibliog. I), solid propellants were not seriously considered for the following reasons:

1. Specific impulse is lower than with liquid fuels.
2. The short burning time may not be possible with solid fuel since it must burn along its entire length, thus increasing the diameter required for passage of the gases.
3. The entire tube of the booster would be heated by burning and since this tube wall would be subject to very high loads, an increase in thickness would be required.

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4. For solid fuels, as compared to liquid fuels, there is more variation in the effective line of thrust so that dispersion would be increased.

While, as indicated above, Bendix argued a good case for liquid propellants, other quarters voiced their opinions with regard to the merits of solid propellants. Consequently, in a report dated 1 October 1947, issued by the Jet Propulsion Laboratory of the California Institute of Technology (Reference 6, Bibliog. I), the following advantages of the solid propellant as compared to the liquid propellant were cited:

1. Rockets propelled by solid propellant are relatively inexpensive in overall cost in comparison to liquid rockets of equivalent type.

2. The solid propellant system can be serviced and operated in the field by relatively unskilled crews after quite brief instructions. Men having special technical skills are not required.

3. The unpredictable movement of the contents of the tanks of a liquid propelled rocket during sharp maneuvers is avoided if solid propelled antiaircraft and antimissile rockets are used.

4. The mass densities of these propellants are between 20 and 55% greater than the average densities of the conventional liquid propellants.

In view of the cited advantages and the difficulties which were being encountered in developing a liquid propelled LOKI Missile at Bendix, the Ballistic Research Laboratories at Aberdeen Proving Ground made a feasibility study on the performance to be expected in the LOKI round if solid propellant replaced the liquid propellant (Reference 7, Bibliog. I). The solid propellant selected was a polysulfide rubber-perchlorate type developed at the Jet Propulsion Laboratory in Pasadena, California. The

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feasibility study indicated that the solid propelled version of LOKI would probably out-perform the liquid driven LOKI Missile.

The contract with the Bendix Corporation called for development of a complete LOKI System, exclusive of fire control, using a liquid fuel rocket. On 29 February 1952, the contract was amended. The amended contract called for the development of an electrical fuze, development of an interim launcher and construction of two test launchers to accommodate solid propellant rockets, and research and development of a liquid fueled rocket.

In June 1952, the prime contractor had essentially completed studies on the use of white fuming nitric acid (WFNA) and various fuel systems. The studies revealed that while these systems were adequate from a performance and energy standpoint, WFNA showed some undesirable decomposition characteristics. The catechol type fuels flow characteristics at low temperatures complicated the injector hydraulics. Because of this, work was being initiated in the use of aromatic amine fuels and red fuming nitric acid as the oxidizer. Also at this time a fairly extensive program on the corrosion resistance of rocket metal components to the combustion gases was underway. (Reference 8, Bibliog. I.)

Studies of the resistance of rocket chamber and nozzle materials to the gases generated by these liquid propellants indicated that 4130 steel was superior to cast aluminum. Coatings of a variety of materials for protecting the rockets were under consideration.

By June 1952, it was recognized that some very basic studies were required on ignition of the liquid propellants. Prompt and spontaneous hypergolic ignition was desired. It was recognized that without prompt ignition, the excess fuel and oxidizer injected into the combustion chamber

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could lead to loss of control when burning started. To solve these problems, a relatively extensive development program was outlined (Reference 9, Bibliog. I). The program dealt primarily with the design of experiments to determine the contributions to ignition lag of the inherent chemical properties of the liquid propellants, and the mixing phenomena as a function of injector design.

On 10 July 1952, the contract with the Bendix Corporation was again amended to include the design and construction of a four-tube launcher, production of up to 320 fuzes, and the providing of new tubes for the LOKI interim launcher.

By November 1952, the Bendix Corporation had succeeded in getting relatively accurate pressure measurements of fuel and acid, as functions of time, being introduced into the combustion chambers (Reference 10, Bibliog. I). Pressure-time curves of the burning process were also recorded. All pressure-time curves exhibited oscillations of various amplitudes, indicating that additional work was required in order to smooth out the introduction of the propellants into the combustion chamber and develop more uniform burning.

In December 1952, technical direction of the project was transferred from ORDTU (Guided Missile Branch, R&D Division, OCO) to Redstone Arsenal.

Up to about October 1953, total government contractual obligations to the Bendix Aviation Corporation amounted to about \$8,314,798.

Reorientation of the LOKI Program

By May 1951 the Aberdeen Proving Ground (APG) was working closely with Bendix in preparation of flight firings of liquid motors. The APG was also assisting in wind tunnel studies on the warhead and in the chemistry of

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combustion processes. After a period of extensive study, including static and flight firings of interim liquid missiles, it became apparent that development was lagging far behind the anticipated schedule (Reference 11, Bibliog. I). After a study of flight firings made at the APG in the summer of 1951, most of the effort was directed toward the solid propellant version of LOKI (Reference 15, Bibliog. I).

Reports by the Ballistic Research Laboratory in 1949 (Reference 7, Bibliog. I) and the Army Field Forces Liaison Office at the Jet Propulsion Laboratory in 1950 (Reference 12) on the use of solid propellant in the LOKI Missile led to a project assignment in this connection at Redstone Arsenal in 1950.

Supporting the decision to continue LOKI development were the results of an analysis on hit probabilities of LOKI relative to some other weapon systems. The superiority of LOKI, as discussed in an APG report (Reference 13, Bibliog. I), is illustrated in Figure 2.

In March 1951, a solid propellant LOKI project was initiated at the Jet Propulsion Laboratory under Contract DA-04-495-ORD-18, with technical supervision by Redstone Arsenal. The program at the Jet Propulsion Laboratory included only the solid propelled booster and warhead development, leaving the launcher fuze development and liquid driven motor at the Bendix Aviation Corporation. It was intended that development of the two missile programs be carried on until one showed decided advancement and chance of success over the other. The plan included flight tests to determine the influence of burning time on dispersion; the effect of separation of the warhead from the booster on dispersion and aerodynamic information for comparison against wind tunnel data; the effect of aerodynamic

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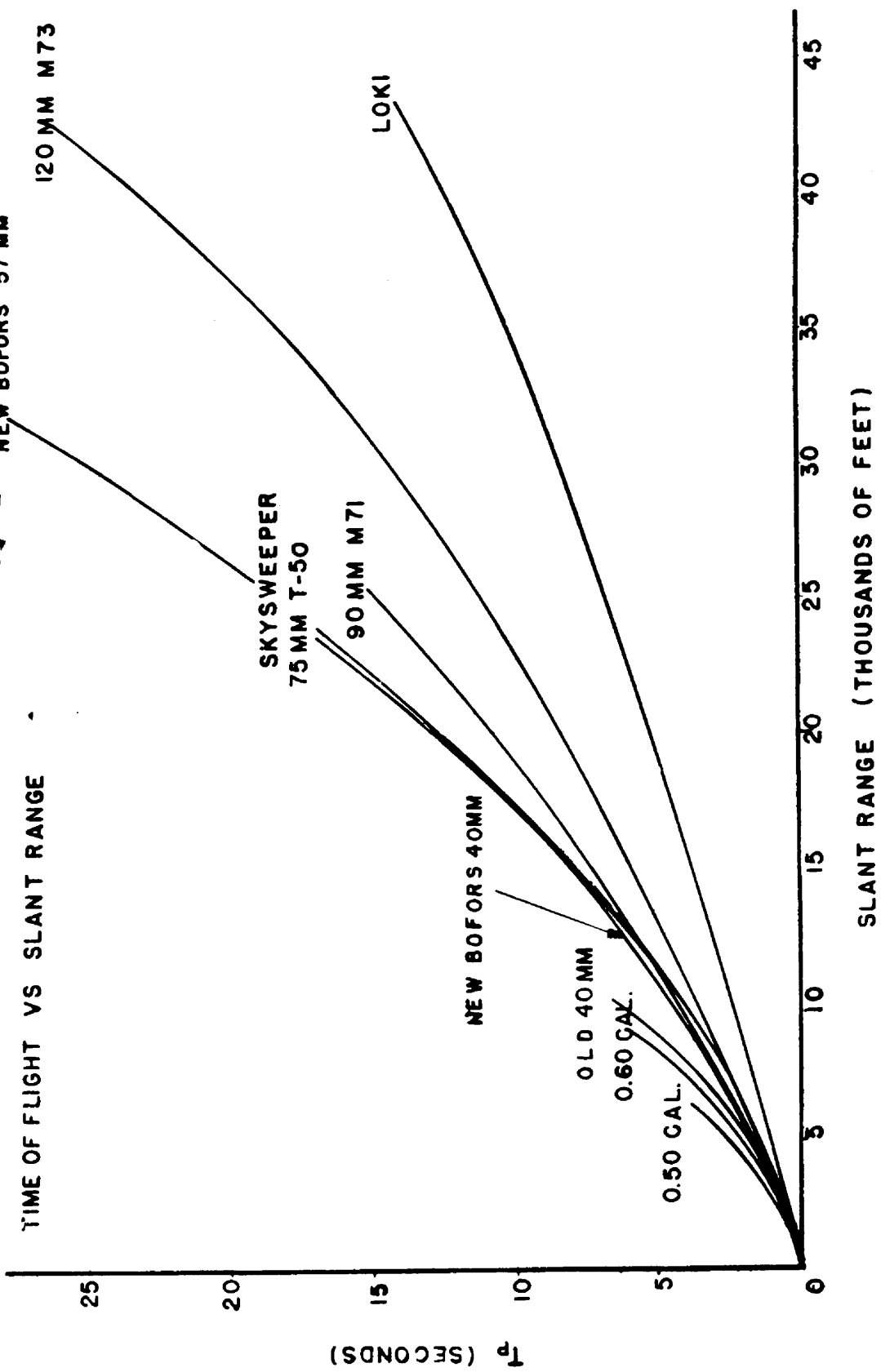


FIGURE 2

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interference between the fins of the dart and booster; the possible influence of aeroelastic deflections upon straightness of the assembly; and optimum rate of spin for offsetting jet malalignment. This contract, DA-04-495-ORD-18, permitted a Government obligation of about \$2,000,000 to the Jet Propulsion Laboratory.

By midsummer 1951, the work on the solid propellant version of the LOKI motor at the Jet Propulsion Laboratory showed considerable promise. (Reference 14, Bibliog. I.) During December 1951 and January 1952, a committee (referred to as the Walker Committee) examined in some detail the LOKI project at the Bendix Aviation Corporation (Reference 15). Following this analysis, the main emphasis of the LOKI power plant was switched to the solid propellant driven vehicle being developed by the Jet Propulsion Laboratory.

In the course of settling on a suitable launcher design, several different arrangements were under consideration by Bendix. These were:

1. A single tube repeater type in which the missiles were brought into firing position on a belt-like arrangement.
2. Magazine type with loaded magazines fed into the breech via tracks.
3. Revolver type having six magazines mounted in such a way that they could be rotated in a horizontal plane.
4. Radial loader in which the launcher automatically picks up loaded magazines in proper sequence, aligns them, rams them in place, fires and proceeds to repeat the cycle until the rockets from six magazines have been fired.

The interim launchers developed for this program used radial type loading arrangements, a model of which is shown in Figure 3.

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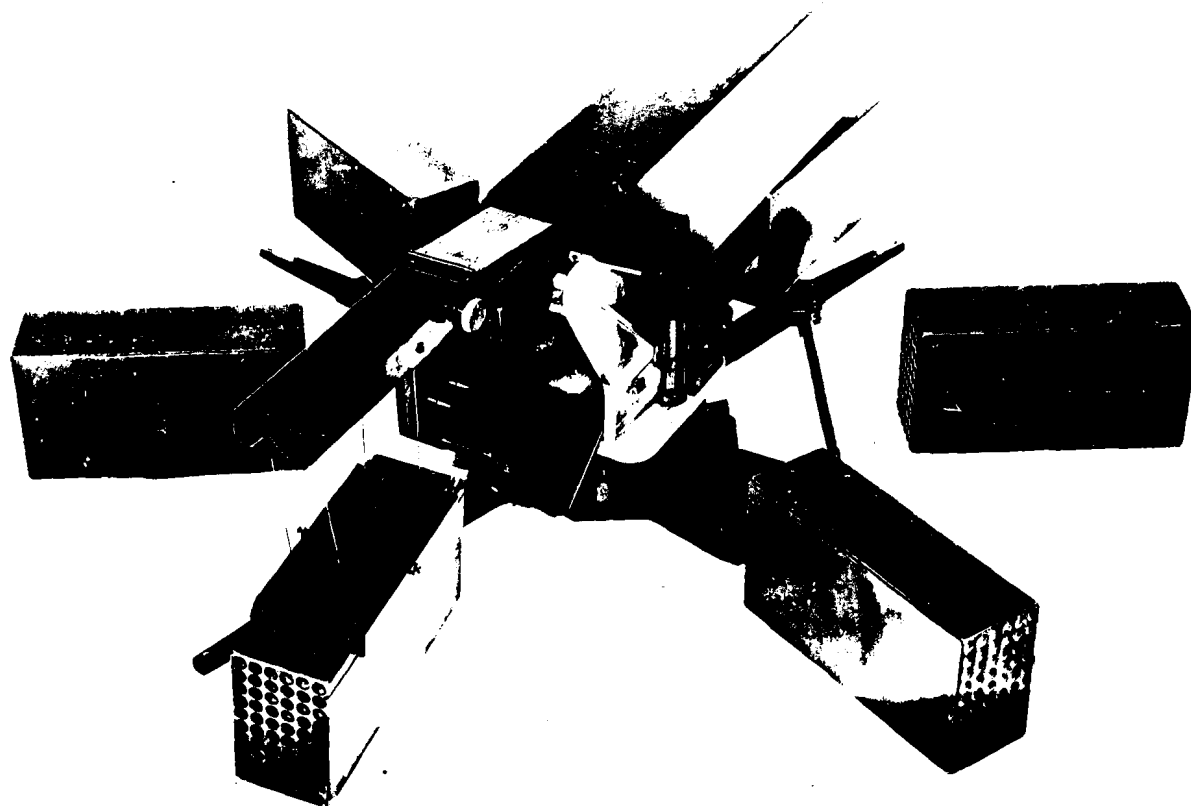


Figure 3. One-Tenth Scale Model of Preliminary Radial Pickup Loader
Showing Clam Pickup closed on a Misaligned Magazine

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A study of a Bendix report on launcher history (Reference 16, Bibliog. I) under Contract W-30-069-ORD-4450 (Project LOKI) between Bendix and the Ordnance Department and originating in November 1947, indicates that at first the effort was at a very moderate level. While a design study on a launcher utilizing an 81-round magazine (Reference 17) was initiated, most of the effort during these early years of the contract were on a liquid fuel missile. In October 1950, the basic concepts for the launcher were established and detailed design and development were initiated. It was recognized that operation of the launcher had to be entirely by remote control and completely automatic. By February 1952, Rocket Launcher, Antiaircraft, T-128 Model I, designed for launching the liquid fuel version of LOKI was in an "advanced" design stage. The artist's conception of this launcher in action is shown in Figure 4.

In view of the fact that in 1952 the solid propellant version of the LOKI Missile was showing more promise than the liquid version, the Bendix Corporation was directed to reorient its launcher development work to make it applicable for use with the solid propelled LOKI. While a number of launcher components were similar regardless of which missile type was to be fired, a fair amount of redesign work became necessary. The major changes were to reduce the number of rounds in the magazine from 64 to 46 and to lengthen the magazine. This was necessitated by the fact that the solid propelled LOKI had greater diameters and lengths than its liquid counterpart. The redesign led to Rocket Launcher, Antiaircraft, T128 Model II.

In order to expedite development of the T128 launcher, it was decided to use and adopt the 90mm antiaircraft mount M2. While a number of problems

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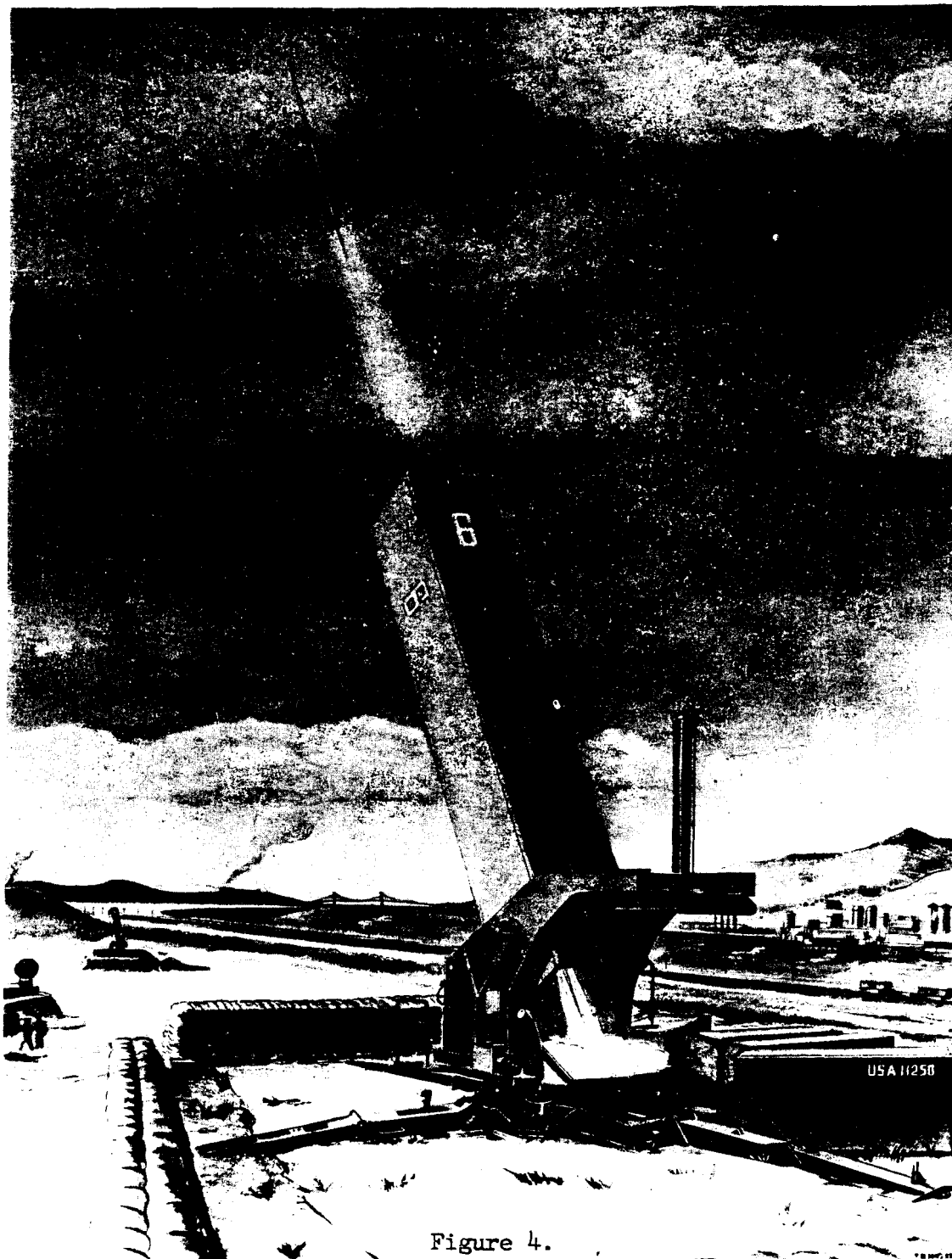


Figure 4.

ARTIST'S CONCEPTION OF T128 AUTOMATIC LAUNCHER

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arose in the modification of this mount, the design engineers were able to realize reasonably good success, as indicated in the context that follows.

In a report dated 5 May 1953 (Reference 18, Bibliog. I), Bendix indicated that the items of first importance were to demonstrate the loading operation and to show the operation of the launcher both in azimuth and elevation. On the basis of expected delivery of subassemblies for use on test rig, launcher No. 1 and magazine, demonstration dates were suggested as follows:

1. Test rig loading and ramming operations - 15 July 1953.
2. Launcher traversing and elevation - 31 August 1953.

These dates permitted a two-week period for a reasonable number of unforeseen difficulties to be met and overcome.

In this same report, Bendix pointed out that the present appropriation, covering the contract period 1 January 1953 to 31 December 1953 and amounting to \$750,838.75, was not adequate to carry the launcher work at the desired level and that an additional \$444,340.06 was required. The total estimated expenditures for the period 1 April 1953 to 31 December 1953 amounted to \$768,465.75. The estimated expenditures broken down in detail for this period included, among other items: \$239,041 for engineering labor; \$13,500 for travel; and a \$50,300 fee.

As indicated in the Bendix launcher history (Reference 16, Bibliog. I), the Antiaircraft T128 Launcher Serial No. 1 was demonstrated in Teterboro, New Jersey for Redstone personnel on 28 October 1953, and then shipped to White Sands Proving Ground for field testing. Launcher Serial No. 2 was being assembled at Teterboro at that time.

In going from Model I to Model II, the following design improvements

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were made, as reflected in size and weight reductions:

| | <u>MODEL I</u> | <u>MODEL II</u> |
|---|----------------|-----------------|
| Weight of Tipping Parts Plus Loaded Magazine (Pounds)..... | 9,500 | 8,800 |
| Launcher Tube Length (Inches)... | 292 | 233 |

Field testing of the launcher pointed to the desirability of making a number of design changes. To make things more difficult, approximately four months working time at White Sands Proving Ground on evaluation of the launcher characteristics under Contract DA-30-069-ORD-1500 were lost in 1955, as a result of extensive lightening damage.

During July and August 1955, an intensive rebuild program was in progress on the Antiaircraft T128 Launcher Serial No. 1. This was necessitated as a result of several problems which were recognized during and after completion of test events 15 through 18. While single rounds were fired successfully, malfunctions occurred during salvo firings (Reference 19, Bibliog. I).

Proper adjustment of the missile retainers resulted in the successful firing of six salvos as specified in test event #18. Ripple firing of all 46 rounds was also successfully concluded. These rounds had inert type warheads propelled by Thiokol production motors and were fired at ambient temperatures (Reference 20, Bibliog. I). On termination of the LOKI Program, nine firing events were completed, among which were several successful multiple magazine events.

The Bendix Corporation also completed the manufacture of launcher No. 2 and shipped it to the Aberdeen Proving Ground. This launcher incorporated the improvements developed during the field test programs using launcher No. 1 (Reference 21, Bibliog. I).

In all fairness it can be stated that the T128 launcher design

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represented a compromise with expediency, in that it was a modification of an existing antiaircraft gun mount which had been equipped with a power control system designed for a different gun mount. Limitations imposed by fixed dimensions in the mount restricted the size of the tube cluster, thereby limiting the number of rocket tubes that could be accommodated. The TL28 launcher, as finally developed, is a 46-tube, semi-mobile launcher equipped with an automatically programmed hydraulic loading system. It weighs approximately 42,300 pounds in the traveling condition and 35,992 pounds, without magazine, when emplaced. Removal of the two-wheeled bogies permit skidding it into cargo aircraft for Phase III airborne operations. The mount is capable of elevation from 0° to 495° and traverse through 360° of azimuth. Each magazine weighs about 2,060 pounds when empty and 3,238 pounds when loaded. The firing circuits are completed through a 92 connector plug at the front end of the center tube. It is estimated that it will require about 40 man-minutes to load 46 loose rockets into the magazine and make the electrical connections.

A general idea as to the success realized in developing the LOKI System and the probability of bringing down enemy aircraft is illustrated in Figure 5, obtained during the 25 April 1955 night firing program (Reference 22, Bibliog. I). Other photographs taken during this firing program indicated very little motion of the muzzle of the mount during firing. A stable mount, distance to the target, projectile flight time and type of fire control used, all contribute to the effectiveness of an antiaircraft system in bringing down hostile aircraft.

Evaluating the performance of the missile with respect to hit probability at high altitudes demanded the best possible cameras, tracking devices

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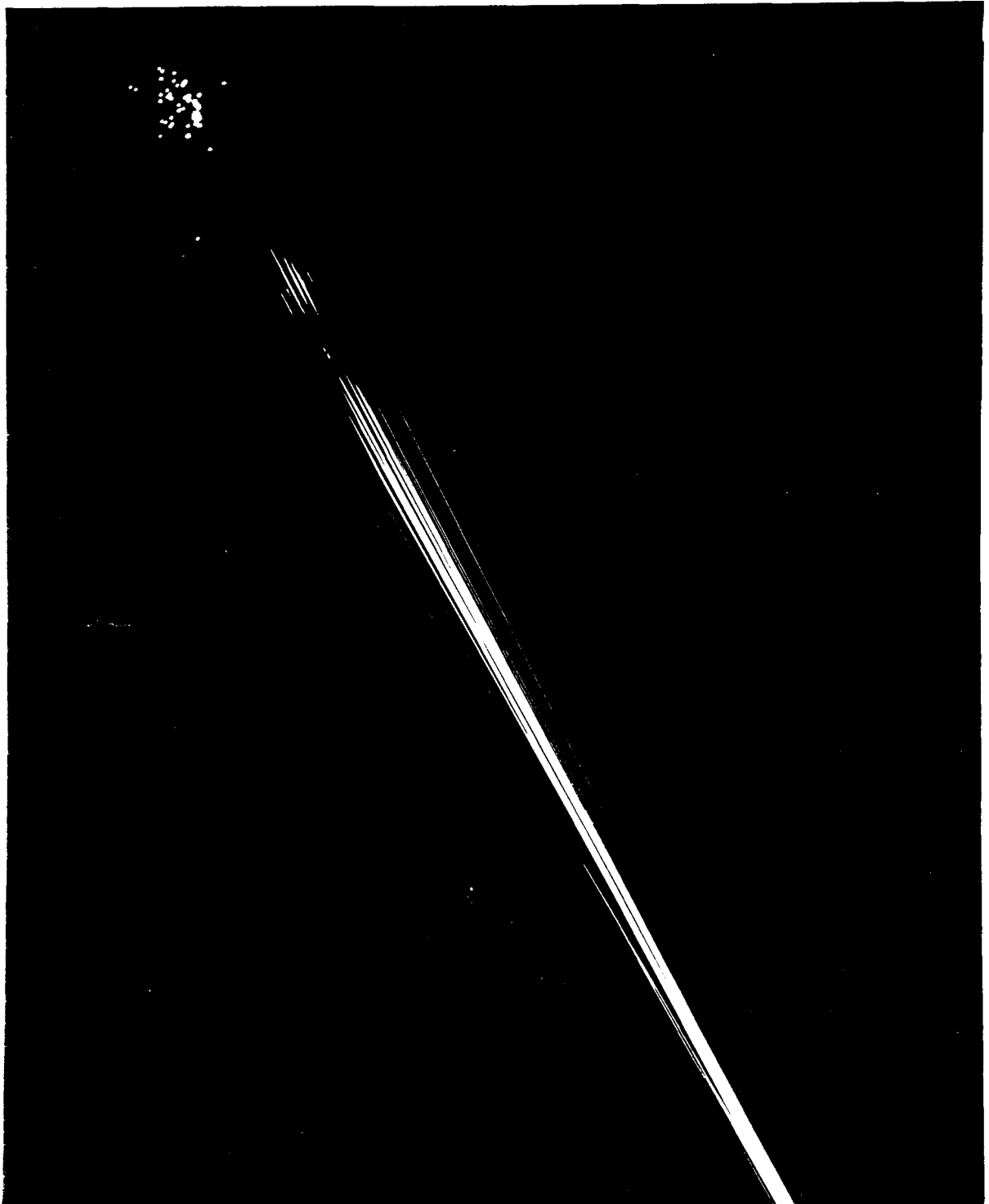


Figure 5. 46-Round Burst Pattern Six Second Time of Flight,
1300 Mils Elevation, 30,000 Feet Slant Range

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and measuring techniques that the White Sands Proving Ground could supply. The burst positions for the 46-round ripple fire shown in Figure 5 were observed from six different ballistic camera stations. Standard production rounds were used; the self-destruction fuze used was designed and manufactured by the Bendix Corporation. The results of the firings of this particular test event showed vertical and lateral probable errors of 6.5 and 6.0 mils, respectively (Reference 23, Bibliog. I).

The importance of obtaining certain detonation of the warhead at an exact time to effectively bring down the enemy missile or aircraft placed a relatively difficult burden on the fuze design developmental agencies. In order to assure the obtaining of a reliable fuze to meet realistic target dates, several contractors were engaged.

According to a Franklin Institute report (Reference 24, Bibliog. I), one of the requirements of the LOKI fuze is a delay of 500 microseconds after impact. The voltage generating device for providing power to initiate the explosive train was a "lucky" element. "Lucky" elements are piezoelectric devices, such as barium titanate which generate voltages when subjected to pressure. The skin temperature of the LOKI round was known to rise as high as 400°F. If the temperature of the lucky element should reach the Curie point (250°F), it would lose its voltage generating properties and become useless on impact. One of the contractors, the Erie Resistor Corporation, determined the internal temperature of the round and found it to be "dangerously" close to the Curie point. Thermal insulation seemed to be the answer.

As outlined in a Redstone report (Reference 25, Bibliog. I), fuzes for the LOKI rocket were to incorporate the following features:

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1. Delayed arming to occur between 300 and 3,000 feet from launcher.
2. Self destruction to occur 32.5/ 2.5 seconds after launching the rocket.
3. Functioning delay on target impact of approximately 0.85 millisecond.

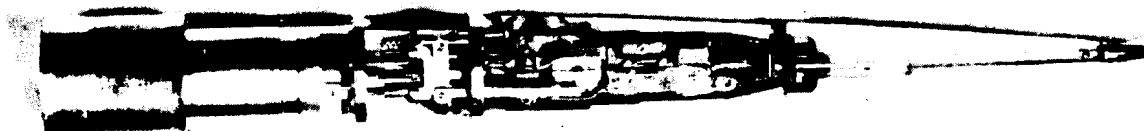
In October and November of 1954, the Stewart-Warner fuze for the LOKI Missile was tested for detonator safety, effects of jolt and jumble, and functioning of the explosive train. The tests indicated that the arming mechanism would not initiate the "explosive train" while the detonator was in the "unarmed position." A redesigned version of this fuze met the military specifications for safety with respect to jolt and jumble testing; however, the fuzes did not function after being jumbled.

An additional fuze development entitled Rocket, PD SD T2041, was initiated by teletype from Redstone Arsenal to Picatinny Arsenal dated 9 May 1952. Under the technical supervision of Picatinny Arsenal, the Eastman Kodak Company was given the responsibility for the design and development work.

This fuze, shown in Figure 6, consists of an arming mechanism designed to arm the fuze when the rocket burns out, a point detonating mechanism designed to function the fuze when it strikes the target, and a mechanism designed to self-destroy the fuze in case the target is not engaged. The fuze status as reported by Picatinny Arsenal in May 1955 (Reference 26) was:

1. The fuze will function on striking 0.020-inch to 0.25-inch 24ST aluminum targets at angles of obliquity from 0 to 70 degrees. Although test results on 0.375-inch thick targets at 70 degrees obliquity were inconclusive, it appears that 50% functioning can be expected on target impact under these conditions.

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T2041 FUZE
(CUTAWAY MODEL)

Figure 6.

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2. After impact with the target, the fuze will detonate the rocket head in approximately 750 microseconds, as a result of which penetration of three feet into the target will result when striking at 4,000 feet per second.

3. The fuze will self-destroy the round after approximately 32.5 seconds time of flight.

4. The fuze will remain unarmed until rocket burn-out (about 3,000 feet).

5. The fuze has satisfied the following military standard tests in addition to ballistic tests conducted to determine that required functioning characteristics had been met:

| | |
|------------------|--------------------|
| Jolt..... | Mil-Std - 300 |
| Jumble..... | Mil-Std - 301 |
| 40-Ft Drop.... | Mil-Std - 302 |
| Vibration..... | Mil-Std - 303 |
| Detonator Safety | (Proposed Mil Std) |

While the Bendix Aviation Corporation, as previously indicated, did some fine work in fuze design, it was generally recognized that the Eastman Kodak Company fuze design for tactical use was showing the greater promise.

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EXECUTION OF PROGRAMS

Development of Solid Propellant Driven LOKI at JPL

In March 1951 at the request of the Ordnance Corps of the Department of the Army (Reference 14, Bibliog. I), the Jet Propulsion Laboratory (JPL) in Pasadena undertook to produce a solid fuel rocket for the LOKI Antiaircraft System. This solid fuel rocket program was initiated when it became apparent that the progress of the original liquid fuel motor under development by the Bendix Aviation Corporation was lagging behind the rest of the system. In the development of the solid-fuel prototype, efforts were made to retain in the missile those characteristics which fitted with the LOKI launching and fire control systems already partially completed.

By June 1951, the design and fabrication studies had progressed to the extent that initial flight tests of the LOKI were being conducted. By May 1952, the tests at JPL had established a design having usable performance, accuracy and reliability. Thus, the prototype design was released to the Ordnance Corps since JPL personnel believed that the work was sufficiently advanced to support the further development of the LOKI System. There was no doubt at that time on the part of JPL personnel but what continued development was required--yet it appeared that in view of the immediate requirement for a usable rocket design, prompt action was advisable. The data on the basic prototype configuration are given in a JPL report (Reference 14, Bibliog. I). In this report, it was stated that while the LOKI booster in the design available at that time was a workable and producible propulsion system, it was not particularly suited for mass production. The following problems were apparent:

1. Fin and nozzle arrangements led to propellant loading difficulties.

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2. Propellant curing time excessive (72 hours).
3. Propellant casting involves separate castings for the motor and head which led to increased costs.
4. Inherent limitations in the graphite nozzle.
5. Seal ring at head joint made of polysulfide was difficult to manufacture.

While preliminary results from ballistic firing indicated that a decrease in fin span from 6.3 to 5.3 inches increased the standard deviation in elevation from 6 to 8 mils, it seemed advisable from space requirements and launcher design to reduce the fin span to 5.3 inches.

The development status of the liquid version of the LOKI Rocket as of 16 May 1951 is indicated in an Industrial Division office memorandum to the Research & Development Division (Reference 27, Bibliog. I). In this memorandum, the Industrial Division expressed some concern because rapid progress in motor development was not being realized. The Industrial Division had budgeted \$500,000 for a Phase II industrial mobilization study.

The Industrial Division problem arose because no items could be considered for production until proven in research and development tests and the funds for the Phase II mobilization had to be obligated prior to 31 June 1951. At approximately this same time, an additional \$500,000 was allocated for an industrial engineering study of rocket motors suitable for use with solid propellants.

On 11 June 1951, the Industrial Division (ORDIM) in Washington advised the Commanding Officer, Redstone Arsenal, by memorandum (Reference 28) that instead of having only a single study on the liquid driven LOKI, an additional study on the solid driven LOKI was desired. The memorandum outlined in considerable detail the nature of the industrial studies required.

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Redstone representatives promptly initiated a survey to locate competent manufacturers to handle the Phase II study (Reference 29, Bibliog. I). Along with an Industrial Division representative in Washington (ORDIM), a Redstone representative visited about 21 manufacturers prior to selecting a contractor for the study.

As noted in a Redstone Arsenal Memorandum for Record (Reference 30, Bibliog. I), considerable discussion occurred prior to agreeing that the Phase II studies on the warheads and liquid propellant version of LOKI should go to the Bendix Aviation Corporation, and that the East Coast Aeronautics Company should make the studies on the launchers and solid propellant version. Interesting viewpoints brought out in the memorandum indicated some concern about breakdown of morale at Bendix should the production opportunity be taken away. It was brought out that the LOKI Rocket was of a new type requiring solution of difficult technical problems and that Bendix had already acquired technical knowledge and facility for aiding in the solution of these problems. It appeared in some quarters at that time that progress might be retarded if the Phase II studies were placed with a new contractor. There was little doubt but what Bendix had well trained technical personnel. It seemed apparent that with strong support by company management, a more satisfactory progress could be obtained. In view of this and the fact that Bendix was the only company that had gained experience in this highly specialized field of study, it appeared logical to assign the Phase II study to the Bendix Corporation.

Thus, to provide hardware for the research and development effort, the Bendix Aviation Corporation under Contract DA-30-069-ORD-173 in July 1951 was directed to carry out Phase II studies on the warhead and the

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liquid propellant version of LOKI. The East Coast Aeronautics Company, also in July 1951, under Contract DA-30-069-ORD-408, was to manufacture motors for use with solid propellants.

In June 1952, under Contract DA-30-069-ORD-748, the East Coast Aeronautics Company was engaged to produce 1200 motors and 835 heads for use in the research and development effort. About the same time, the East Coast Company was engaged to produce several thousand additional motors under Contract DA-30-069-ORD-824. Through contractual arrangements, the Government was to deliver the East Coast motors to the Thiokol Chemical Corporation for loading with polysulfide-perchlorate type propellant. Since the East Coast Aeronautics Company was encountering technical difficulties in motor manufacture, motor delivery which was to start in May 1953 was delayed until July 1953. The reasons for the late deliveries are discussed in more detail in a Status Report of Contract ORD-824 (Reference 31, Bibliog. I).

The research and development efforts in evaluation of the missile performance in flight and mass firing necessary for the preparation of the firing tables and fire control system all suffered severe setbacks because of the inability of the East Coast Aeronautics Company to deliver metal parts of high quality as scheduled. The research and development effort suffered additional setbacks when the Thiokol Chemical Corporation was unable to load rounds as scheduled. The extent of the loading difficulties encountered by the Thiokol Corporation is reported in considerable detail in a Redstone Arsenal Memorandum for Record (Reference 32, Bibliog. I). Thus, while it appeared in some quarters that the research and development work on the missile metal parts and propellant composition was

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incomplete in the latter part of 1952, telescoping metal parts and propellant loading production with research and development seemed desirable in order to meet reasonable dates for end item availability. This led to a number of problems. The propellant loading problems encountered by the Thiokol Chemical Corporation are closely related to difficulties in suitable metal parts production at the East Coast Aeronautics Company.

In August of 1954, the status of the LOKI Program was interpreted by White Sands Proving Ground (WSPG). In this report (Reference 33, Bibliog. I), it is stated that the LOKI prototype system was supposed to be through a system test by January 1956, a date set by Staff. The prediction, made at that time, that the long time required for modification of the M33 fire control system would make it difficult to meet the 1956 date, proved correct. System testing as of 30 June 1955 pointed to the spring of 1956. The report also indicated that the JPL development prototype had not quite met the original system requirement for a rocket with an accuracy of 6 mils circular probable error. The principal areas of concern in the ammunition field in August 1954 were:

1. Dispersion characteristics and surface wind response.
2. Warhead lethality and reliability.
3. Field handling problems under all environments.

While work on the field handling problems was initiated prior to 30 June 1955, items 1 and 2 were being deferred pending fuze acceptance.

Tests had been conducted on the susceptibility of the booster to tactical field conditions of gunfire, fire and explosive shocks. It was shown that the booster would generally ignite, rupture and burn erratically. No high order detonations were observed.

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As of August 1954, the Bendix Aviation Corporation had initiated field testing of the T128 prototype launcher at WSPG. The contractor's research and development test program was slanted primarily toward a proof of the structural and functional design under ripple fire conditions. Difficulties were encountered in the firing circuit and the automatic loading system did not function properly after the ripple of 22 rounds. It was stated that the contractor's R&D tests would leave a good deal to Ordnance to test before the acceptability of the launcher could be determined, even as a prototype for use in general system evaluation. In any event, a launcher redesign study was under consideration in August 1954. Watertown Arsenal, Frankford Arsenal, and Bendix were to do this work for Redstone Arsenal. At that time, the program for engineer-user tests called for initial concentration on dispersion, flight path deflection as a function of tracking rate, firing accuracy to be followed by road and environmental tests.

By October 1952, the solid propellant version of the LOKI Rocket was in a sufficiently satisfactory state of development to permit serious thought on collection of data for establishing firing tables and dispersion. At this time, the WSPG submitted a test plan for establishing this data (Reference 34, Bibliog. I).

The magnitude of the problem can be appreciated when it is realized that the trajectory firing program called for the determination by actual flight tests of: (1) the variations of the drag and ballistic coefficients for the LOKI Missile; (2) the effect of variation of those parameters which would be required to compute a firing table for the LOKI and to determine the missile dispersion; and (3) the general missile characteristics such

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as stability, yaw, and spin programs. A careful analysis of the equations of motion for the LOKI revealed that the significant parameters affecting its flight were as follows:

1. Parameters which can be controlled in the field:
 - a. Missile and propellant temperature.
 - b. Launcher elevation angle and azimuth.
2. Parameters which are fixed by design specifications:
 - a. Weight of the propellant.
 - b. Weight of the missile empty.
 - c. Weight of the dart.
 - d. Stability and spin rate of the missile.
 - e. Normal dispersion of the missile.
 - f. Degree of accuracy with which the launcher can be set in elevation and azimuth.
3. Parameters which cannot be controlled but which can be chosen within suitable limits:
 - a. Surface winds.
 - b. Winds aloft.
 - c. Ambient air temperatures.
 - d. Atmospheric pressure.

Advice obtained from the Ballistic Research Laboratories at Aberdeen Proving Ground indicated that the basic requirements for compilation of the firing table were:

1. Firings should be conducted at a minimum of four different quadrant elevation angles.
2. A minimum of five points must be obtained on trajectories for each of the quadrant elevation angles in 1 above. The five points desired must be approximately equally spaced in time from launching to 30 seconds time of flight. The desired points are at 6, 12, 18, 24, and 30 seconds time of flight.
3. A minimum of ten statistically significant data rounds must be fired at each of the points in 2 above.

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4. Burnt velocity must be obtained for each round fired for each of the conditions in item 2 above.
5. Propellant temperature conditioned firings be conducted at the maximum and minimum safe firing temperatures and at two intermediate temperatures.
6. A minimum of ten statistically significant data rounds must be fired for each of the conditions in item 5 above.
7. Surface wind effects be determined by firings at various wind speeds.

The program, as interpreted by WSPG, indicates that the firing table studies suffered because the production people had not been able to maintain the tolerances realized in the R&D rounds. It was believed in August 1954 that the Ballistic Research Laboratories would complete reduction of trajectory data very shortly. An accurate analysis of the dispersion characteristics of the LOKI Missile was required before a satisfactory fire control system could be developed. Following the completion of the trajectory data studies, it appeared that the Bell Telephone Laboratories would require about fifteen months to modify the M33 fire control system to the LOKI. Thus, the system test target date was established for the early part of 1956.

The research and development effort suffered materially as a result of the inability of the East Coast Aeronautics Company to manufacture high quality metal parts. The very fact that the research and development work had to be telescoped with production to realize a reasonable target date for the end item led to complications. Continuous developmental changes introduced after manufacturing had started made it difficult for the East Coast Company to maintain delivery schedule. The first metal parts turned out by this producer appeared inferior, as indicated by a Redstone Memorandum for

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Record (Reference 32, Bibliog. I). Determination that the manufacturing performance by the East Coast Aeronautics Company was not up to contract standards led to a study of that company by the Inspector General, a representative of the New York Field Office (Reference 35, Bibliog. I). On the basis of this study, necessary changes were made which resulted in production of acceptable metal parts for the LOKI program.

The importance of reduction in weight of the LOKI Missile prompted the design engineers to recommend relatively thin fins for stabilization. This decision met with some criticism by the propellant loading agency due to difficulty in loading the rounds without damaging the fins.

As indicated above, while the East Coast Aeronautics Company and the Thiokol Chemical Corporation were developing mass production techniques for the LOKI booster metal components and propellant, respectively, the Jet Propulsion Laboratory continued improving the round through research and development effort.

An important part of this Jet Propulsion Laboratory program was a systems analysis to determine the effects of such variables of the system as launching velocity, spin rate, aerodynamic stability and booster burning time on the dispersion and performance of the missile. To assist in this systems analysis, five types of power plants were built. These power plants had essentially the same external configurations and were designed to separate from and impart a high velocity to a 6.3-pound dart. They were driven by various polysulfide-perchlorate type propellants. Important characteristics of these power plants are:

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| <u>Characteristic</u> | <u>Phase I</u> | <u>Phase II</u> | <u>Phase III</u> | <u>Phase IA</u> | <u>Phase IIA</u> |
|---|----------------|-----------------|------------------|-----------------|------------------|
| Burning Time (Sec)..... | 0.80 | 1.69 | 0.354 | 0.82 | 1.86 |
| Average Thrust (Lb)..... | 3340 | 1610 | 7260 | 3640 | 2043 |
| Propellant Weight (Lb)... | 12.5 | 13.5 | 15.5 | 14.6 | 17.2 |
| Power Plant Weight Less Fins (Lb)..... | 17.66 | 18.71 | 20.65 | 19.71 | 22.49 |
| Burning Velocity (80°F) (Ft/Sec)..... | 4500 | 4500 | 4450 | 5050 | 5600 |

The following is a summary of the LOKI power plant production and flight testing under Jet Propulsion Laboratory cognizance:

| | <u>Phase I</u> | <u>Phase II</u> | <u>Phase III</u> | <u>Phase IA</u> | <u>Phase IIA</u> |
|---|----------------|-----------------|------------------|-----------------|------------------|
| Number Produced..... | 860 | 421 | 421 | 28 | 118 |
| Number Flight-Tested..... | 1204 | 294 | 159 | 7 | 32 |
| Number of Failures During Flight Test..... | 37 | 9 | 19 | 2 | 4 |
| Rounds Since Last Failure | 66 | 230 | 4 | 1 | 21 |

On termination of the program, the Jet Propulsion Laboratory had also essentially completed the performance calculations of two optimized power plant designs. One of these called for a tapered motor tube for improving aerodynamic stability and facilitating loading of propellant into the chamber. Unlike the older designs, this optimum design study resulted in a design which permitted loading the propellant and withdrawing of the mandrel from the nozzle end of the rocket.

As early as 1953, Ordnance was initiating work to learn the extent of damage resulting from the dropping of the LOKI booster in the vicinity of the firing batteries and adjacent areas. (Reference 36, Bibliog. I.) Test plans were developed for measuring the velocity and destructiveness

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of boosters returning to the ground after both low and high angle firings. It was recognized that in a number of instances the batteries could be so arranged that the boosters would normally fall in city parks or dumps. In other instances, however, it would be desirable to be able to shatter the booster before it returned to the ground, and thus reduce the hazard. Under development for this purpose were non-metal frangible type booster cases.

With regard to the status of the LOKI propellant as of 30 April 1955, both JPL-131 and Thiokol T22 propellants were being used in the LOKI motor. A subcommittee meeting held at JPL at that time recommended that one propellant be established for use with the LOKI motor (Reference 37, Bibliog. I). The propellant selected for this purpose was propellant A, which also carried the designations Thiokol TRX-142-1 and JPL-135. This propellant consisted of 71.5% ammonium perchlorate, 26.3% LP33 polysulfide polymer, 1.7% GMP, 0.3% iron oxide, and 0.2% sulfur. Four different mixes were evaluated under a variety of processing conditions. The inspection results were as follows:

| | Mix Number | | | |
|------------------------------------|---------------|---------------|---------------|---------------|
| | <u>H 2641</u> | <u>H 2643</u> | <u>H 2645</u> | <u>H 2647</u> |
| Motors Loaded..... | 60 | 58 | 57 | 60 |
| Loaded Motors Accepted..... | 9 | 4 | 1 | 6 |
| <u>Motors Rejected Because of:</u> | | | | |
| Liner..... | 0 | 6 | 6 | 9 |
| Voids..... | 7 | 26 | 9 | 4 |
| Shrinkage..... | 27 | 16 | 17 | 19 |
| Cracks..... | 10 | 2 | 17 | 6 |
| Liner Ring..... | 4 | 0 | 0 | 4 |
| Torn Propellant..... | 3 | 3 | 4 | 12 |
| Leakage of Propellant..... | 0 | 1 | 2 | 0 |
| Metal Parts..... | 0 | 0 | 1 | 0 |

Total Motors Loaded: 235; Total Accepted: 20; Total Rejected: 215.

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In view of the high percentage of rejects (92%), it was concluded that more work would be required on this composition before it would be acceptable. The loaded motors were turned over to the Government and fulfilled part of a production contract.

With regard to propellant T22, data on the performance under static testing of LOKI motors loaded by the Thiokol Chemical Corporation under Ordnance Contract DA-01-021-ORD-3924 are given in a Redstone Arsenal Research & Development Report (Reference 38, Bibliog. I). Figure 7, taken from this report, illustrates the gradual change in potential of rounds produced over a period of about one year. Some concern was expressed regarding the ease with which process control could be maintained in view of the number of rounds falling beyond the upper control limit during the latter part of the loading period.

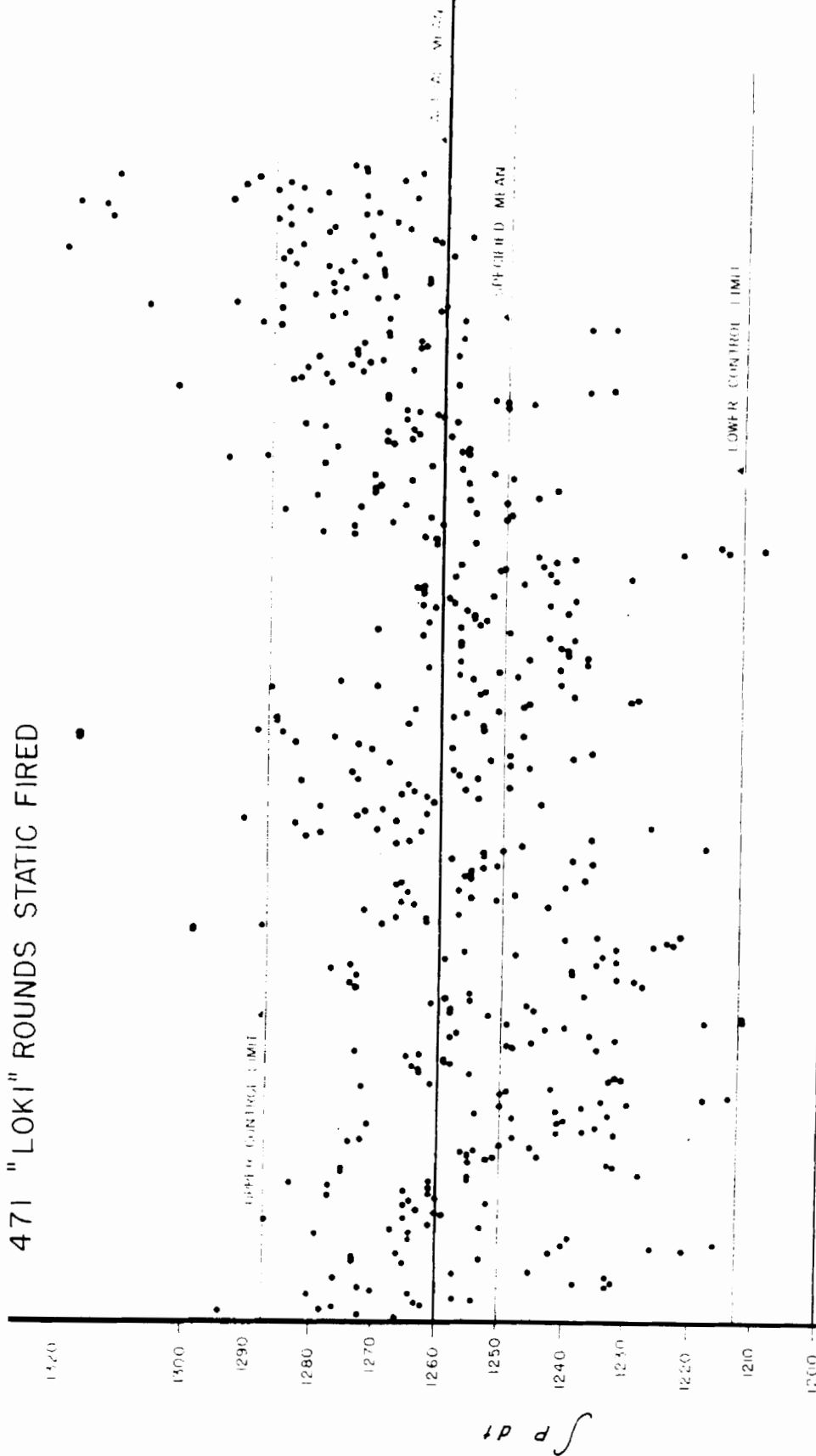
From these data it became evident that the transition from research and development to mass production would not be easy. In an effort to better resolve these problems, Thiokol served in an advisory capacity to the LOKI project in addition to the contractual programs outlined above (Reference 2, Bibliog. I). Since January 1952, representatives of Thiokol had been in attendance at all major conferences and offered their assistance on all problems concerning the missile.

Regarding the progress being made on the small caliber liquid fueled rocket motor, it is stated in a Bendix report dated October 1954 (under Contract W-20-069-ORD-4450 R), that since March 1952 the liquid propellant rocket development program has been directed toward a more fundamental study of the problems of ignition, combustion and performance which "must be resolved in order to place the development of a tactical rocket propelled

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QUALITY DISTRIBUTION CHART

471 "LOKI" ROUNDS STATIC FIRED



NO. OF ROUNDS

Figure 7

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missile on a sound basis." As stated in this report, Bendix believed that liquid propellant rockets can provide an attractive alternative to other propulsion devices for artillery and small missiles (Reference 39, Bibliog. I). As of October 1954, red fuming nitric acid-ammonia had been successfully fired over a temperature range from -65° to $+70^{\circ}$ F. Stable combustion and smooth start transients were obtained over the entire temperature range. The program planning included extending the combustion studies of the nitric acid-ammonia up to 160° F. Development problems included nozzle erosion and leaking of the liquid propellant.

Anemometer, Wind Velocity Computer & Wind Correction Computer Development

It was recognized that surface winds would affect the trajectory of the LOKI Rocket. To compensate for this wind effect, the North American Instruments, Inc. was engaged under Contract DA-04-495-ORD-352 to develop wind measuring equipment and equipment for transmitting data to the M33 anti-aircraft Fire Control System. In this contract, a prototype anemometer was developed, completely redesigned and adapted for field use. The design included mechanisms to permit non-variant performance over a wide temperature range. Heating elements were provided for prevention of icing. External connections were designed for use by field personnel in heavy clothing. An environmental test program for the anemometer was devised, and an operating manual and complete drawings for the CM-4 Anemometer were submitted. Preparations for checking out a second anemometer were underway on contract termination. Prior to contract termination, the wind correction computer was completed, and the wind velocity computer was converted for operating with the redesigned CM-4 Anemometer. Time was available for only a few performance tests (Reference 40, Bibliog. I).

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Fire Control System

By 1950 the T33 Fire Control System was in a state of development which permitted its consideration for use with LOKI. Thus the LOKI would employ radar tracking and could be fired either day or night.

A LOKI System study was authorized under Contract DA-30-069-ORD-941 dated 26 February 1953, with the Bell Telephone Laboratories, Inc. Included in the study were recommendations for modification of the M33 Antiaircraft Fire Control System for use with the LOKI Rocket. The M33 is an integrated, self-contained system for controlling the fire of medium and heavy antiaircraft artillery batteries. Originally developed for control of 90mm and 120mm gun batteries, it appeared suitable for modification for use with the LOKI Rocket.

The discontinuance of the LOKI program prevented adaption of the wind measuring and correcting equipment, developed by the North American Instruments Company, to the M33 Fire Control System.

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REVIEW AND EVALUATION OF PROGRAMS

In July 1951, the Rand Corporation submitted a study entitled "Low Altitude Local Defense" (Reference 41, Bibliog. I). At that time, it appeared that by 1953 "interceptors" would provide cheaper and more effective defense than would guns or unguided rockets against offensive aircraft and missiles at medium and high altitudes. It appeared that proper maneuvers, well within the capabilities of aircraft and their present instruments, would reduce the effectiveness of unguided weapons by factors which might be as large as several thousand (Reference 42). It was predicted that by 1955 the guided missiles would operate effectively against evading or non-evading aircraft.

Two years later, it was becoming apparent that the Rand analysis was proving correct and that the unguided missiles like the LOKI were gradually losing ground in favor of guided missiles.

At the request of OCO, a meeting was held at the Jet Propulsion Laboratory on 4 February 1952, for the purpose of exchanging technical information and defining responsibility for continuation of LOKI development (Reference 45, Bibliog. I). Redstone Arsenal Government personnel indicated that the Thiokol Corporation was assigned a process study for production of rocket motors; the East Coast Aeronautics Company was assigned a production study and fabrication of a number of metal parts for boosters; and the Jet Propulsion Laboratory was assigned the tasks of the development of the missile and technical advice to the production agencies. At this meeting, Redstone Arsenal personnel also proposed that trajectory firings be conducted promptly in order to provide the designers of the Fire Control Equipment with ballistic data. Personnel from the Jet Propulsion

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Laboratory stated that in order "to meet the proposed schedule, it would be necessary to decide upon a production rocket design before exploring the ballistic problem in its entirety." JPL personnel believed that any decisions made during the next six months (i.e., prior to August 1952) would have to be regarded as preliminary. Regarding the collection of ballistic trajectory data, it was brought to light that, as of 4 February 1952, the White Sands Proving Ground had not had the time to reduce the LOKI flight data collected in December 1951. Conclusions reached at the committee meeting were as follows:

1. Redstone Arsenal would assist the Jet Propulsion Laboratory in obtaining a local source of loaded flight-test booster rockets for use in the research program.
2. Every effort would be made to improve the delivery time for reduced flight-test data from WSPG to JPL.
3. Redstone Arsenal would act as coordinator for all agencies involved. Communications would be carried on directly among agencies, with a copy of each letter to Redstone, except that suggestions for policy changes or design changes affecting production would be made directly to Redstone Arsenal.
4. Regarding the program:
 - a. JPL would decide on a tentative aerodynamic configuration by 1 April 1952, and flight tests of the new configuration would be started in April. The decision as to booster fin span and launcher tube diameter would be made by 1 June 1952, provided flight-test data from the April firings were available by the middle of May.
 - b. The material and construction of the dart aft section would be

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decided upon by 1 April 1952.

c. The Bendix Aviation Corporation would continue development tests of the fuze, with modifications to ensure arming at the accelerations provided by the 0.8-second rocket motor. The design of the launcher mount and mechanism would be continued, but the design of the tube cluster would await the decision as to tube diameter.

d. The East Coast Aeronautics Company would begin delivering booster and warhead metal parts, according to the present design, in May 1952. Material procurement will start immediately.

e. The Thiokol Corporation would begin loading booster rockets in June 1952. Thiokol would obtain material and fabricate the necessary mandrels and casting equipment.

f. The Ordnance Corps would expedite the contract for ten radar beacons at Melpar, and an order for 500 beacons would be placed as soon as possible.

g. The investigation of alternate tracking methods would be continued. If an optical system proved practical, JPL would develop the missile equipment and the Ballistic Research Laboratory would be responsible for the ground installations.

h. Arrangements for dart impact tests at the Naval Ordnance Test Station, Inyokern, California, would be completed as soon as possible.

5. Another planning meeting was to be held at the Jet Propulsion Laboratory during the first week in April 1952.

In March 1953, the Ballistic Research Laboratories (BRL) made a comparison of various weapons for use against bombers (Ref 43, Bibliog I).

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The conclusions reached were essentially that against single non-maneuvering targets, NIKE is superior to the 127/60 gun which, in turn, is superior to LOKI. Against single maneuvering targets, NIKE is far superior to both of the other weapons. Against tight formations, NIKE is inferior to LOKI which, in turn, is slightly inferior to the 127/60 gun, and against loose formations all three weapons are about equal. In this study, LOKI was not recommended for use against low flying aircraft. When all weapons are compared in the defense of divisions near the front lines, it appears that NIKE has a potential effectiveness far above that of any other weapon. As a result of these studies, guided missile studies were intensified. However, BRL recommended that both the 127/60 gun and LOKI development programs be completed, since it was recognized that unforeseen engineering difficulties might cause either system to fail.

About this same time, the Operations Research Office of the John Hopkins University submitted an Air Defense Special Study (Reference 44, Bibliog. I). This report dealt with the evaluation of the Army research and development program in the field of air defense. The best estimates of the air threat and the effectiveness and costs of various antiaircraft weapons were discussed. In this report it was recommended that the LOKI development should be continued only until NIKE proved operationally satisfactory, both for the Continental United States and the field army. The importance of getting effective antiaircraft weapons for altitudes of 1,000 feet and less was stressed. It was recommended that a low altitude surface-to-air guided missile system be explored.

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TERMINATION OF THE LOKI PROJECT

While it appears that the basic concept of the LOKI Rocket was a good one, the progress made in the interim 1947-1952 period generated some concern. Anxiety continued to mount somewhat when delays in delivery of metal parts and loaded rounds occurred. The difficulties encountered by the Bendix Aviation Corporation in redesigning the launcher under development for the liquid driven LOKI to meet requirements of the solid driven LOKI added to the delays. In turn, delays in data reduction at White Sands Proving Ground delayed preparation of firing tables necessary for use in developing the fire control system. After promises made in good faith, regarding expected missile quality and delivery dates, could not be met, a lack of confidence developed. Reports of progress being made on guided missiles such as the HAWK and NIKE I prompted Ordnance to discontinue the LOKI program.

On 11 August 1955, a meeting was held at Redstone Arsenal for the purpose of discussing the orderly transfer of various LOKI project functions from Redstone Arsenal to the Ordnance Ammunition Command (Reference 46, Bibliog. I). The transfer was in accordance with OCO 19-55 and OCO 16-55. At this meeting it was agreed that the Redstone Industrial Division, on about 1 October 1955, would furnish the Ordnance Ammunition Command complete procurement records of LOKI loadings at Longhorn and all available records on the tactical fuze which Research & Development would release for procurement on 1 September 1955. The balance of the procurement records would be forwarded to the Ordnance Ammunition Command on or about 1 November 1955. The OAC agreed to inform Redstone Arsenal of the desired disposition of 117 LOKI Phase II rocket motors and 64 heads, metal parts only,

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that were on hand at Redstone Arsenal and which were procured on East Coast Aeronautics Contract ORD-408.

As of November 1955, the Chief of Staff had approved termination of LOKI and Ordnance was directed to do so. Accordingly, Redstone Arsenal was advised by teletype to expeditiously terminate all work on Project TU2-1012. In closing out the LOKI program, Redstone Arsenal wired the following message to the Office, Chief of Ordnance on 16 November 1955:

"Final effort on LOKI project during October 1955, devoted to closing out tests in progress at proving grounds and reorienting work on contract. Jet Propulsion Laboratory notified to terminate work and write final report. Bendix Aviation Corporation advised to ship Number 2 launcher to Aberdeen Proving Grounds for storage and write final report. North American Instruments advised to terminate development by October 31, 1955. Wind equipment will be forwarded to Redstone for test. Launcher Number 1 at White Sands Proving Ground to be forwarded to Redstone for storage."

On termination of the LOKI program the status was essentially as follows:

Motors. LOKI motors were undergoing extensive surveillance at Picatinny Arsenal under Project TU2-4D.

Fuze. The Eastman Kodak Company fuze was believed ready for the engineering test phase. The development agency was desirous of procuring about 500 fuzes for this study.

Launcher. One launcher was undergoing tests at White Sands Proving Ground and an additional launcher had been released for shipment by the Bendix Aviation Corporation.

Fire Control System. The modification of the M33 fire control system for use with LOKI was incomplete.

Metal Parts and Propellant. The manufacture of metal parts and propellant loading was in a reasonably satisfactory state. Metal parts designed to reduce manufacturing cost had not been evaluated.

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29. RSA Memorandum covering a review of LOKI Project status and a survey to locate manufacturers competent to handle Phase II Study. Also see ORDIM Travel Report, dated 28 June 1951.
30. RSA Memo for Record, Phase II Study on Rocket HEAA, 76mm, T208 (LOKI), dated 6 July 1951.
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CHAPTER II

INDUSTRIAL PROGRAM

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INTRODUCTION

Action with respect to the release of segments of the LOKI System for industrial procurement was primarily for the purpose of furthering and supporting the research and development program. As of 30 June 1955, the development phase had not been completed and the system as such had not been selected for procurement as a weapon. Instead, industrial activity was confined to those areas pertaining to production engineering studies and quantity procurement of rocket motor and dart (or head) assemblies. The purpose of quantity procurement of projectiles was twofold:

1. Support research and development mission agencies in the continued development and refinement of propellants, fuzes, explosives, launchers, fire control mechanisms, etc., as well as the system as a whole.

2. Provide a means of obtaining industrial data with respect to production know-how, equipment check-out, propellant loading know-how, refinement of production techniques, and facility requirements for mobilization.

Onset of the Korean conflict, undoubtedly, was a major contributing factor in advancing the release of the initial industrial program early in 1951. Certain disadvantages, such as the high expenditure of funds inherent in the development of a system by means of program telescoping, and the attendant failure to achieve timely development releases, neutralized the effect and purpose of the accelerated effort to a considerable degree.

Since the industrial program is divided in two separate categories,

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i.e., production engineering followed by production, and each phase allied so closely with the research and development program, each part is treated separately with appropriate references being made to particular segments of the Research & Development Chapter.

EXECUTION OF THE INDUSTRIAL PROGRAM

Production Engineering Procurements

The initial "kick-off" of the Industrial Procurement Program early in 1951 resulted in the allocation of \$1,000,000 to Redstone Arsenal for procurement of production engineering studies on the solid and liquid propellant designs of the LOKI Rocket. Selection of capable contractors was now the problem.

In approaching the problem of finding manufacturers qualified to do an outstanding job of conducting Phase II studies on the missile, a preliminary study was undertaken to determine the status of the missile development and the nature of the manufacturing problem. Knowledge of the status of development was necessary in order to be able to inform the prospective contractor regarding the nature and magnitude of the problem and to indicate the degree of coordination necessary between the manufacturing and functional development activities. Knowledge of the manufacturing problem was also necessary to insure elimination of manufacturers lacking the technical qualifications and the kind of experience demanded by the product. It was desired that this investigation be concluded with an accumulated list of manufacturers whose product design and mass production accomplishment would insure the development of production designs, methods and equipment adapted to produce LOKI rockets in quantity

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at the ultimate minimum of cost. The problem was somewhat complicated by the fact that the magazine as well as the rocket was to be included in the Phase II study. The magazine required facilities and manufacturing techniques differing quite materially from those required by the rocket and warhead.

Further consideration of this proposed procurement, insofar as the liquid propelled design was concerned, necessitated a review of the accomplishments of the R&D contractor (Bendix Aviation Corporation). Although Bendix had developed and recommended a small liquid propelled missile (see Chap. I, pp. 4-7), an examination of the proposed model indicated that a great deal of redesign would be required to put it in satisfactory condition for manufacture. There was a need to reduce the number of parts and assembly operations, and to rework detailed parts designs to adapt them to the most economical means of manufacture, without affecting performance. These requirements called for the services of an organization with a demonstrated capacity for the exercise of imagination in the coordination of product design with manufacturing techniques.

Mobilization requirements for the LOKI missile were very substantial and the anticipated problems called for an organization that would be complete and competent in the fields of planning, scheduling, materials handling, tool development, automatic production machine development, manufacturing methods development, quality control, and other details of manufacturing procedure as applied to mass production. It was important that the organization be one very familiar with the problems of handling aluminum. It should be an organization that demonstrated an

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alertness to and a capacity for adapting to its use advanced manufacturing techniques. Many of the opportunities for cutting cost of the LOKI lay in the adapting of very recently developed techniques for resistance welding, cold extrusion or forging of aluminum, etc. Manufacturing versatility applicable to mass production was also an important qualification.

The above requirements all pointed toward the most likely sources as being among the manufacturers of automobiles, domestic appliances, out-board motors, kitchen utensils, and other producers of durable consumer goods. These sources, however, were not exclusive. A preliminary industrial survey conducted by Redstone Arsenal resulted in a list of firms believed best qualified to perform the required Phase II studies. Proposals were solicited and obtained from the following firms:

Bendix Aviation Corporation, Teterboro, N. J.
East Coast Aeronautics, Inc., Mount Vernon, N. Y.
Gibson Refrigerator Co., Greenville, Michigan
Firestone Steel Products Co., Akron, Ohio
Brown & Bigelow Co., St. Paul, Minnesota
National Pressure Cooker Co., Eau Claire, Wisconsin
International Harvester, Chicago, Illinois
Hudson Motor Car Company, Detroit, Michigan
Motor Products Corporation, Defiance, Ohio

An evaluation of the proposals was made by the Office, Chief of Ordnance in conjunction with procurement and technical representatives of Redstone Arsenal. As a result of this evaluation, the following contracts were awarded by New York Ordnance District in July 1951:

Liquid Design - Bendix Aviation Corporation
Contract DA-30-069-ORD-173

Solid Design - East Coast Aeronautics, Inc.
Contract DA-30-069-ORD-408

The awarding of these contracts, to some extent, served as "pouring oil

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upon the water" with respect to the two schools of thought advocating the liquid driven rocket versus the solid propellant design. A resume' of these pro and con technical opinions is provided in Chapter I on pages 6-7 and 26-27.

In general, the results achieved under these two Phase II engineering contracts led to the selection of the solid propellant missile system as the one to be developed for tactical use. This selection, however, was based on the fact that developmental progress was attained more quickly in the field of solid propellants and not because the liquid design was rejected. After selection of the solid propellant design, action was taken to terminate the contract for the liquid design.

Production Procurements

Fiscal Year 1952

The initial results of the Phase II study on the solid propelled design of the LOKI Rocket as performed by the East Coast Aeronautics Company under Contract ORD-408 prompted Research & Development to conduct further investigations into the possibility of developing a complete weapon system around the solid propellant design. Figure 1 shows the proposed development schedule. As a result, a requirement for a relatively small quantity of motors and heads was initiated and assigned to the Industrial Division (OCO) for procurement purposes. Even though this requirement was for the primary purpose of supporting launcher development, its size was considered sufficient to promote the accumulation of industrial planning data.

This requirement of 1200 motors and 835 heads was subsequently funded to Redstone Arsenal for procurement purposes and resulted in the

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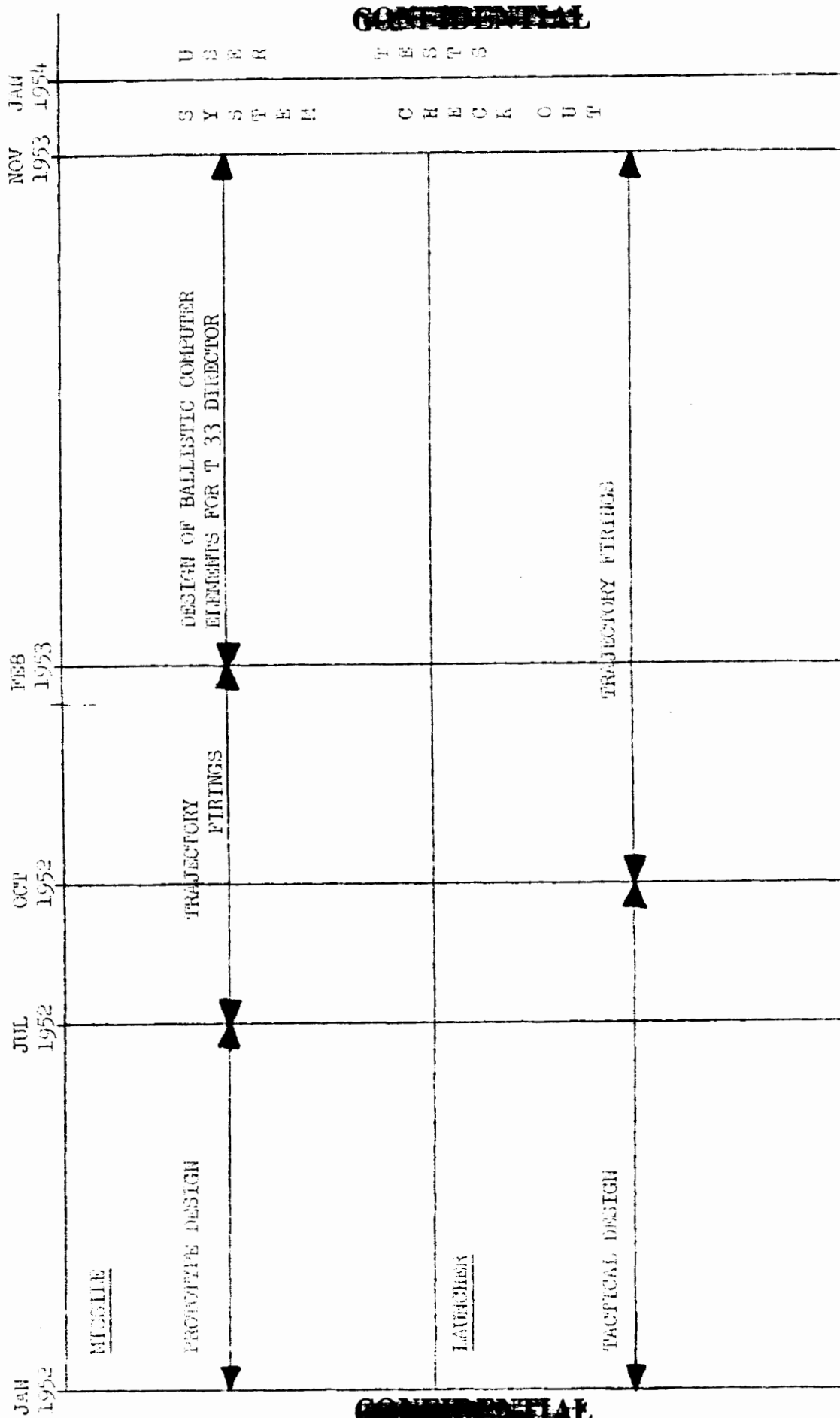


FIGURE 1. LCCI DEVELOPMENT SCHEDULE

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awarding of Contract DA-30-069-ORD-748 to East Coast Aeronautics by the New York Ordnance District, in June 1952.

Almost simultaneously with this procurement of metal parts, Contract DA-01-021-ORD-3205 was placed with the Thiokol Chemical Corporation, Redstone Division, for propellant loading 835 motors out of the 1200 sets of parts being procured from East Coast. Work directives were also issued to Picatinny Arsenal and Evans Signal Laboratory for loading and assembly of most of the heads with conventional high explosives and special beacon devices. East Coast was to assemble the balance of the heads with beacon devices under the contract.

Metal parts manufacture and loading operations were delayed, to some degree, by technical difficulties; however, 835 rounds were delivered to the R&D agency at Redstone Arsenal and these rounds were subsequently utilized in system engineering tests at White Sands Proving Ground. Motor parts in excess of the 835 delivered to Research & Development were used by the Thiokol Chemical Corporation in production check-out of loading operations and other tests.

This initial production contract provided a preview of the difficulties that were to be forthcoming in LOKI missile production and loading; viz., close tolerances and loading techniques.

Almost concurrently with the initiation of a requirement for LOKI rounds for system development purposes, additional requirements were calculated for purposes of exhaustive systems check-out and user tests. This requirement for 27,000 complete rounds was also processed to Redstone Arsenal for procurement purposes and resulted in an additional award to East Coast Aeronautics by the New York Ordnance District under Contract

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DA-30-069-ORD-824 for the metal parts. This procurement for parts was supplemented with the award of Contract DA-01-021-ORD-3924 to the Thiokol Chemical Corporation, Redstone Division, for motor loading and the issuance of a work directive to Picatinny Arsenal for head loading.

The organizational merger of East Coast Aeronautics with Barium Steel Corporation in the fall of 1952 led to difficulties in view of the record of Barium Steel. An investigation, conducted by the New York Field Office of the Army Inspector General, resulted in a recommendation by that office in January 1953 that all contracts with this company be cancelled (see Reference 35, Bibliog. Chapter I). This recommendation was taken into consideration in the light of technical developmental accomplishments at that time and the fact that an urgent requirement existed for metal parts which the contractor could apparently deliver much quicker than if the contracts were terminated for convenience of the Government and reprocured from another source having no LOKI experience at all. Consequently, the decision was made to retain the contractual relationship with East Coast Aeronautics for the time being.

Delivery of the metal parts was scheduled to begin in March 1953, but prior to this date it became apparent that East Coast would fail in its schedule commitments. The obvious areas of difficulty were:

1. The company did not have the production engineering skill and know-how to accomplish an order of this size.
2. The company did not have sufficient facilities to produce satisfactory parts at the required rate of 4,000 complete sets per month.
3. The Ordnance development agency issued large numbers of Engineering Change Orders in an attempt to improve the performance of the missile.

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Performance by East Coast under Contract ORD-824 was very unsatisfactory throughout most of Calendar Year 1953. In an effort to resolve the problems and establish a realistic delivery schedule, periodic meetings were held with contractor representatives for the purpose of establishing a forecast of deliveries for the immediately following months. Month after month the schedule was missed until the late fall of 1953, by which time the failure of East Coast to make delivery of metal parts had caused a serious interruption in the system developmental phase. At this time, serious consideration was given to terminating the contract although such action would have further delayed system development. In January 1954, after establishing another forecast delivery schedule, the contractor was informed that if this schedule was missed immediate action would be initiated to terminate the contract for default. Deliveries after this date were, for the most part, acceptable and satisfactory, both quantity and quality wise, and the contract was allowed to run to completion.

Hindsight being superior to foresight, it is easy to say that the interest of the Government would have best been served by terminating the East Coast contracts in January 1953 and reprocurring from new sources. In fairness to the decision as made, it must be acknowledged that the status of the missile design, technical wise, at that time did not lend itself to the procurement from any new source with the firm expectation that quantity acceptable deliveries could be made in less than 12 months from contract date.

The delays in quantity delivery of metal parts naturally resulted in an equivalent delay in the start of motor loading operations under

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Thiokol Contract ORD-3924. Even after metal parts were delivered in sufficient quantities to sustain continuous motor loading operations, the contractor experienced recurring difficulties in meeting established forecast delivery schedules. Two of the major factors contributing to these difficulties were: (1) pilot line operations not readily adaptable to mass production requirements, and (2) the contractor was primarily a research and development facility and his experience in mass production was practically non-existent.

As a consequence, the program suffered further delays and regular monthly meetings were held with the contractor in an attempt to establish firm delivery schedules upon which system development could proceed. For a period in excess of a year, there were continuous negotiations with the contractor toward supplementing the loading contract to reflect a revised delivery schedule; however, there never was a meeting of minds between contractor and Government personnel, with the result that the original contract was not supplemented. The delays in metal parts deliveries and those incident to motor loading conspired to place the program about two years behind schedule. As a result, in May 1955 requirements for loaded and assembled missiles under the FY 1952 program were reduced from 27,000 rounds to approximately 9,600 rounds. This resulted in the termination, for convenience of the Government, of Contract ORD-3924 with Thiokol Chemical Corporation effective 30 June 1955.

With most emphasis being placed on alleviation of the problems in metal parts production and motor loading, little attention was given to head loading at Picatinny Arsenal. Delays in motor loading, however, made it necessary to adjust the warhead loading schedule in an attempt to

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keep it in phase with motor deliveries. As production of loaded motors fell further and further behind, safety factors at Picatinny Arsenal and the unknown storage life of the loaded head influenced the decision to abandon the loading schedule for an on-call delivery requirement. As of 30 June 1955, deliveries of inert and conventional high explosive warheads were slightly behind the motor deliveries, with a sufficient quantity scheduled for delivery shortly thereafter to bring the two loaded components into phase. Slightly in excess of 17,000 sets of warhead metal parts and containers were in storage awaiting resumption of loading operations as needed.

Fiscal Year 1953

By late 1952, the projected requirements for solid propelled LOKI Rockets had been determined as an additional 30,000 rounds. This requirement was transmitted to Redstone Arsenal early in 1953 for procurement purposes as the Fiscal Year 1953 Procurement Program. Metal parts were procured by close competitive negotiation and the award made in May 1953 to the Whitin Machine Works, Whitinsville, Massachusetts, under Contract DA-19-020-2904 issued by the Boston Ordnance District. Delivery performance under this contract was considered satisfactory with the exception of minor schedule slippage which was due to pilot lot acceptance difficulties.

Concurrent with the awarding of the metal parts contract, funds were transmitted to the Ordnance Ammunition Command for financing a supplemental agreement with Thiokol Chemical Corporation, Longhorn Division, under Contract DA-41-110-ORD-200 for loading the 30,000 LOKI motors and assembly of the complete round. Loading under this contract was originally scheduled

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to start in January 1955, but due to construction difficulties at Longhorn Ordnance Works and some delay on the part of Redstone Arsenal in issuing revised loading specifications, the schedule was revised to start in October 1955.

The requirement for loading the 30,000 warheads under the FY 1953 program was also placed on Picatinny Arsenal, but the delivery schedule was suspended pending the start of motor loading at Longhorn.

In November 1955, a review was made of the status of system development in the light of latest military requirements and a decision was made to terminate the LOKI Project at the most economical point in the production. Consequently, operations at Longhorn were limited to pilot lot loading and no additional warheads were loaded at Picatinny Arsenal.

Disposition of LOKI facilities, tooling, and component material is being held in abeyance pending the screening by other services for determination as to whether any such items may be utilized in experimentation or developmental programs requiring similar materials.

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CHAPTER III

FIELD SERVICE PROGRAM

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GENERAL SUPPLIES

The LOKI Missile, HEAA, 76mm, T220 launching and fire control equipment, as such, have not been received in Field Service stocks. These items in existence are considered research and development equipment.

The Ordnance Weapons Command, Rock Island, Illinois, was assigned the maintenance responsibility for the Launcher, Rocket, Antiaircraft, T128, by the Office, Chief of Ordnance. Ordnance Corps Order No. 22-55, dated 1 June 1955 (Mission of the Ordnance Weapons Command), officially established this maintenance responsibility.

In the event that the LOKI Missile is authorized for future procurement and delivery to Field Service, the following text material may be utilized as a source for preparing publications and/or for training purposes:

1. Report Number 57-4450, Notes on Materiel, Launcher, Rocket, AA, T128, dated 30 April 1954. These notes were prepared by the Eclipse-Pioneer Division, Bendix Aviation Corporation, Teterboro, New Jersey.

2. Instructors Guide, Training Course T-128 Launcher, prepared in 1954 by the Bendix Aviation Corporation.

Ordnance training peculiar to the LOKI System had not been accomplished for the following reasons:

1. Lack of firm information concerning acceptable design of the missile and industrial production cut in dates for delivery to Field Service.

2. Since LOKI ground and fire control equipment and complete round rockets were generally similar to like items already in the supply system, it was felt that training of personnel could be accomplished by simply

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modifying existing training programs to fit the LOKI System. However, special emphasis would have been given the promulgation of a training program in those instances where an existing program was not adaptable to the LOKI System.

3. It was contemplated that as the LOKI System was developed, the requirements for a training program would be developed accordingly. This was to be accomplished in accordance with paragraphs 3b and 2001.1d of Ordnance Corps Order No. 30-53.

AMMUNITION

The LOKI was established as a free-flight rocket by OCM 32030, dated 19 February 1948. The responsibility for stock control, storage, surveillance and maintenance of free-flight rockets was inherent in the functions assigned to the National Stock Control & Maintenance Point/Ammunition at its inception in December 1949. In accordance with this concept, the Commanding Officer, Redstone Arsenal, was advised by the Office, Chief of Ordnance that the Field Service Ammunition Division, Raritan Arsenal, was assigned these functions.¹ The Field Service activity was transferred from Raritan Arsenal to the Ordnance Ammunition Command (ORDLY-Q) in 1954. This subject is further discussed in a letter from OCO to Redstone Arsenal, subj: "Project LOKI TU2-1012," file 00471.9/1593 (ORDDW-TRP RSA 470/4788), dated 26 August 1952.

Only stock control functions were performed, since there was a limited number of complete rounds produced and these were shipped directly to users.

¹ Ltr fr OCO to CO RSA, File 00 471.94/961 (C), subj: "Stock Control, Storage, Surveillance, Maintenance and Issue of LOKI Free Rocket," dated 4 Feb 52.

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The priority of supply in all instances was directed by higher headquarters and shipping orders were written accordingly.

As of 30 June 1955, 4,896 Motors, Rocket, 76mm, T2006 (LOKI) were in storage at the Redstone Depot, Huntsville, Alabama. However, in effect, these motors were not Field Service items for issue, since they were maintained in storage for research and development tests. Head, Rocket, HEAA, 35mm, T2023 (LOKI), and Head, Rocket, 35mm, T2023 (LOKI), Inert, were received in Field Service storage for short periods of time while awaiting shipping orders to the user for research and development tests. A total of 6,712 heads were procured and delivered for R&D test. Non-tactical LOKI Missiles were shipped for R&D test on Field Service shipping orders.

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CHAPTER IV

CONTRACT COST SUMMARY

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LOKI R&D AND INDUSTRIAL CONTRACTS

The prime contractors performing major portions of the research and development work on the LOKI System are listed in Figure 1. In addition to the contributions of these contractors, various governmental agencies (OCO; Redstone, Picatinny, Frankford and Watertown Arsenal; and White Sands and Aberdeen Proving Grounds) contributed through technical control, supervision of contracts, and the supplying of engineering and test services. As shown in Figure 1, the total cost of R&D contracts with private concerns amounted to \$18,325,867.05. This, of course, does not include expenditures incurred under Industrial Division contracts, nor those expended through direct Government operations.

A chronological breakdown of the cost of the LOKI Industrial Program by commercial contract is presented in Figure 2. The costs incurred in the Industrial Program are hardly indicative of more than that relatively large amounts of funds are required to initiate mass production of a new item.

While the hopes for obtaining a completed antiaircraft weapon system based on LOKI was not realized, even at this writing considerable interest by several agencies in use of the LOKI Rocket for probing the upper atmosphere is apparent. These fortunate circumstances stem in no small way from the highly commendable work done by personnel at the Jet Propulsion Laboratory in developing a high velocity booster. Besides this, considerable hardware and engineering know-how is now available for these studies.

Thus, the story of an interesting missile study, resulting in many useful scientific and engineering facts, is concluded.

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LOKI RESEARCH AND DEVELOPMENT CONTRACTS (SUPPLIES AND SERVICES)

| Contractor | Contract No. | Date Contract Executed | Contract Amount | Type of Contract | Item | Delivery Period | Total Dollars Expended Thru November 1955 | Status of Contract |
|-------------------------------------|---|------------------------|-----------------|------------------|---|-----------------------|---|--------------------|
| Bendix Aviation Corporation | W-30-069-ORD-4450 | 28 Nov 47 | \$10,592,993.52 | CPFF | Liquid Propelled Rocket, Mount and Launcher | 28 Nov 47 - 31 Dec 54 | \$10,578,033.45 | Complete |
| California Institute of Technology | DA-04-495-ORD-18, Supp's 2, 8, 12, 14, 18, 23, 31, and 39 | 5 Oct 50 | 3,416,901.00 | CR | Propellants | N/A | 3,416,901.00 | Complete |
| R. Hoe & Co., Inc. | DA-30-069-ORD-136 | 9 Apr 51 | 171,000.00 | FP-Form IV | Launcher Mount | 9 Dec 51 - 31 Oct 53 | 171,000.00 | Complete |
| Grand Central Aircraft Co. | DA-04-495-ORD-331 | 5 Jun 52 | 600,579.49 | CPFF | Rocket Metal Parts | 6 Jun 52 - 1 Jun 53 | 595,551.72 | Complete |
| Thickol Chemical Corporation | DA-01-081-ORD-76 | 13 Jun 52 | 340,346.00 | CPFF | Booster Improvement | N/A | 340,346.00 | Complete |
| North American Instrument Co., Inc. | DA-04-495-ORD-352 | 25 Jun 52 | 239,145.00 | CPFF | Wind Measuring System | N/A | 232,005.34 | Complete |
| East Coast Aeronautics, Inc. | DA-30-069-ORD-928 | 28 Jun 52 | 94,794.00 | CPFF | Fiber Glass Booster | 28 Jun 52 - 31 Dec 53 | 94,501.75 | Complete |
| Stewart-Warner Corporation | DA-11-022-ORD-1134 | 22 Jan 53 | 188,189.80 | CPFF | Fuze Development | 22 Jan 53 - 31 May 55 | 188,189.80 | Complete |
| Horning-Cooper, Inc. | DA-04-495-ORD-496 | 6 Jul 53 | 393,250.69 | CPFF | Rocket Metal Parts | 6 Jul 53 - 30 Jun 55 | 389,725.62 | Complete |
| Grand Central Rocket Company | DA-04-495-ORD-494 | 22 Jul 53 | 552,871.16 | CPFF | Rocket Parts & Rounds | Sep 53 - 15 May 55 | 511,712.21 | Complete |
| Bendix Aviation Corporation | DA-30-069-ORD-1268 | 11 Dec 53 | 2,127,334.64 | FP-Form IV | Launcher, Rocket & Parts | Oct 54 - Aug 55 | 494,653.54 | Partial Term. |
| Grand Central Rocket Company | DA-04-495-ORD-551 | 14 Jun 54 | 32,890.06 | CPFF | Boosters | 14 Jun 54 - 1 Oct 54 | 32,201.44 | Complete |
| Bendix Aviation Corporation | DA-30-069-ORD-1413 | 4 Nov 54 | 31,919.46 | CPFF | Fabricate Impact Fuzes | 1 Mar 55 | 9,877.71 | |
| Bendix Aviation Corporation | DA-30-069-ORD-1500 | 1 Jan 55 | 449,459.69 | CPFF | Launcher | N/A | 483,262.35 | Complete |
| Bendix Aviation Corporation | DA-30-069-ORD-1501 | 1 Jan 55 | 159,711.96 | CPFF | Fuze | N/A | 156,230.71 | Complete |
| Bendix Aviation Corporation | DA-30-069-ORD-1517 | 4 Jun 55 | 49,930.94 | CPFF | Launcher Components | N/A | 27,266.95 | Term. Notice |
| Bendix Aviation Corporation | DA-30-069-ORD-1540 | 10 Jun 55 | 1,515.00 | FP | Instrument Repairs | 17 Jun 55 | None | |
| Westinghouse Electric Corporation | DA-36-032-ORD-10897 | 23 Jun 55 | 2,634.30 | FP | Electric Motors | 20 May 54 | 2,634.28 | Complete |
| Grand Central Rocket Company | DA-04-495-ORD-672 | 24 Jun 55 | 58,683.17 | CPFF | Booster Loading | N/A | 50,703.97 | Complete |
| Horning-Cooper, Inc. | DA-04-495-ORD-677 | 28 Jun 55 | 16,282.00 | FP | Rocket Parts | Aug - Oct 55 | 16,282.00 | Complete |
| Eastman Kodak Company | DAI-30-115-501-ORD (P) 329 | | 251,636.36 | CPFF | Fuze Development | 9 Apr 53 - 1 Aug 55 | 251,636.36 | Complete |
| American Machine and Foundry Co. | DA-30-069-ORD-1033 | 23 Mar 53 | 309,318.00 | CPFF | Launcher Parts | N/A | 280,920.85 | |
| | | TOTAL: | \$20,061,296.24 | | | | \$18,325,867.05 | |

CPFF - Cost Plus Fixed Fee
CR - Cost Reimbursable
FP - Fixed Price

FIGURE 1
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LOKI INDUSTRIAL CONTRACTS (SUPPLIES AND SERVICES)

| Contractor | Contract No. | Date Contract Executed | Contract Amount | Type of Contract | Item | Delivery Period | Total Dollars Expended Thru November 1955 | Status of Contract |
|--------------------------------|--|------------------------|-----------------|------------------|---------------------------------|-----------------|---|--------------------|
| Lexington Aviation Corp. | DA-30-069-CRD-177 | 12 Jul 51 | 616,500.00 | CPFF | Prod. Eng. - Missile | One Year | 55,638.77 | |
| East Coast Aeronautics, Inc. | DA-30-069-CRD-178 | 12 Jul 51 | 670,956.00 | CPFF | Prod. Eng. - Missile & Magazine | Jul 51 - Oct 53 | 645,746.45 | |
| East Coast Aeronautics, Inc. | DA-30-069-CRD-179 | 9 Jun 52 | 742,669.49 | CPFF | Missile Metal Parts | Sep 53 - Nov 53 | 387,424.28 | |
| East Coast Aeronautics, Inc. | DA-30-069-CRD-180 | 9 Jun 52 | 5,278,944.02 | CPFF | Missile Metal Parts | Dec 53 - Feb 55 | 1,700,111.87 | |
| Thiokol Chemical Corp. | DA-01-021-CRD-3045 | 16 Jun 52 | 243,017.96 | CPFF | Motor Loading | Jul 52 - Sep 53 | 243,017.96 | Complete |
| Thiokol Chemical Corp. | DA-11-173-CRD-3046 Supp's 4, 5, and 6 | 25 Sep 52 | 968,800.00 | CPFF | I/A/P, Motor T2006 | As Scheduled | 968,800.00 | Complete |
| Thiokol Chemical Corp. | DA-01-021-CRD-3047 | 2 Jun 53 | 1,937,610.80 | CPFF | Motor Loading | Jan 53 - Jun 55 | 1,827,610.00 | Terminated |
| Whitin Machine Works | DA-10-020-CRD-3048 | 27 May 53 | 1,792,759.44 | FP-Form ITB | Missile Metal Parts | Jan 54 - Aug 55 | 1,786,530.95 | Complete |
| The James-Patterson Corp. | DA-1-28-017-501-502-503-504-505-506-507-508-509-510-511-512-513-514-515-516-517-518-519-520-521-522-523-524-525-526-527-528-529-530-531-532-533-534-535-536-537-538-539-540-541-542-543-544-545-546-547-548-549-550-551-552-553-554-555-556-557-558-559-560-561-562-563-564-565-566-567-568-569-570-571-572-573-574-575-576-577-578-579-580-581-582-583-584-585-586-587-588-589-590-591-592-593-594-595-596-597-598-599-600-601-602-603-604-605-606-607-608-609-610-611-612-613-614-615-616-617-618-619-620-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-636-637-638-639-640-641-642-643-644-645-646-647-648-649-650-651-652-653-654-655-656-657-658-659-660-661-662-663-664-665-666-667-668-669-670-671-672-673-674-675-676-677-678-679-680-681-682-683-684-685-686-687-688-689-690-691-692-693-694-695-696-697-698-699-700-701-702-703-704-705-706-707-708-709-710-711-712-713-714-715-716-717-718-719-720-721-722-723-724-725-726-727-728-729-730-731-732-733-734-735-736-737-738-739-740-741-742-743-744-745-746-747-748-749-750-751-752-753-754-755-756-757-758-759-760-761-762-763-764-765-766-767-768-769-770-771-772-773-774-775-776-777-778-779-780-781-782-783-784-785-786-787-788-789-790-791-792-793-794-795-796-797-798-799-800-801-802-803-804-805-806-807-808-809-810-811-812-813-814-815-816-817-818-819-820-821-822-823-824-825-826-827-828-829-830-831-832-833-834-835-836-837-838-839-840-841-842-843-844-845-846-847-848-849-850-851-852-853-854-855-856-857-858-859-860-861-862-863-864-865-866-867-868-869-870-871-872-873-874-875-876-877-878-879-880-881-882-883-884-885-886-887-888-889-890-891-892-893-894-895-896-897-898-899-900-901-902-903-904-905-906-907-908-909-910-911-912-913-914-915-916-917-918-919-920-921-922-923-924-925-926-927-928-929-930-931-932-933-934-935-936-937-938-939-940-941-942-943-944-945-946-947-948-949-950-951-952-953-954-955-956-957-958-959-960-961-962-963-964-965-966-967-968-969-970-971-972-973-974-975-976-977-978-979-980-981-982-983-984-985-986-987-988-989-990-991-992-993-994-995-996-997-998-999-1000 | 17 Jun 53 | 8,517.90 | FP | Containers | Jun 53 - Sep 53 | 8,517.90 | Terminated |
| United Can Co., Inc. | DA-1-28-017-501-502-503-504-505-506-507-508-509-510-511-512-513-514-515-516-517-518-519-520-521-522-523-524-525-526-527-528-529-530-531-532-533-534-535-536-537-538-539-540-541-542-543-544-545-546-547-548-549-550-551-552-553-554-555-556-557-558-559-560-561-562-563-564-565-566-567-568-569-570-571-572-573-574-575-576-577-578-579-580-581-582-583-584-585-586-587-588-589-590-591-592-593-594-595-596-597-598-599-600-601-602-603-604-605-606-607-608-609-610-611-612-613-614-615-616-617-618-619-620-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-636-637-638-639-640-641-642-643-644-645-646-647-648-649-650-651-652-653-654-655-656-657-658-659-660-661-662-663-664-665-666-667-668-669-670-671-672-673-674-675-676-677-678-679-680-681-682-683-684-685-686-687-688-689-690-691-692-693-694-695-696-697-698-699-700-701-702-703-704-705-706-707-708-709-710-711-712-713-714-715-716-717-718-719-720-721-722-723-724-725-726-727-728-729-730-731-732-733-734-735-736-737-738-739-740-741-742-743-744-745-746-747-748-749-750-751-752-753-754-755-756-757-758-759-760-761-762-763-764-765-766-767-768-769-770-771-772-773-774-775-776-777-778-779-780-781-782-783-784-785-786-787-788-789-790-791-792-793-794-795-796-797-798-799-800-801-802-803-804-805-806-807-808-809-810-811-812-813-814-815-816-817-818-819-820-821-822-823-824-825-826-827-828-829-830-831-832-833-834-835-836-837-838-839-840-841-842-843-844-845-846-847-848-849-850-851-852-853-854-855-856-857-858-859-860-861-862-863-864-865-866-867-868-869-870-871-872-873-874-875-876-877-878-879-880-881-882-883-884-885-886-887-888-889-890-891-892-893-894-895-896-897-898-899-900-901-902-903-904-905-906-907-908-909-910-911-912-913-914-915-916-917-918-919-920-921-922-923-924-925-926-927-928-929-930-931-932-933-934-935-936-937-938-939-940-941-942-943-944-945-946-947-948-949-950-951-952-953-954-955-956-957-958-959-960-961-962-963-964-965-966-967-968-969-970-971-972-973-974-975-976-977-978-979-980-981-982-983-984-985-986-987-988-989-990-991-992-993-994-995-996-997-998-999-1000 | 30 Jun 53 | 262,631.00 | FP | Containers | Sep 53 - Mar 55 | 253,952.14 | Complete |
| Eastern Tool & Mfg. Co. | DA-1-28-017-501-502-503-504-505-506-507-508-509-510-511-512-513-514-515-516-517-518-519-520-521-522-523-524-525-526-527-528-529-530-531-532-533-534-535-536-537-538-539-540-541-542-543-544-545-546-547-548-549-550-551-552-553-554-555-556-557-558-559-560-561-562-563-564-565-566-567-568-569-570-571-572-573-574-575-576-577-578-579-580-581-582-583-584-585-586-587-588-589-590-591-592-593-594-595-596-597-598-599-600-601-602-603-604-605-606-607-608-609-610-611-612-613-614-615-616-617-618-619-620-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-636-637-638-639-640-641-642-643-644-645-646-647-648-649-650-651-652-653-654-655-656-657-658-659-660-661-662-663-664-665-666-667-668-669-670-671-672-673-674-675-676-677-678-679-680-681-682-683-684-685-686-687-688-689-690-691-692-693-694-695-696-697-698-699-700-701-702-703-704-705-706-707-708-709-710-711-712-713-714-715-716-717-718-719-720-721-722-723-724-725-726-727-728-729-730-731-732-733-734-735-736-737-738-739-740-741-742-743-744-745-746-747-748-749-750-751-752-753-754-755-756-757-758-759-760-761-762-763-764-765-766-767-768-769-770-771-772-773-774-775-776-777-778-779-780-781-782-783-784-785-786-787-788-789-790-791-792-793-794-795-796-797-798-799-800-801-802-803-804-805-806-807-808-809-810-811-812-813-814-815-816-817-818-819-820-821-822-823-824-825-826-827-828-829-830-831-832-833-834-835-836-837-838-839-840-841-842-843-844-845-846-847-848-849-850-851-852-853-854-855-856-857-858-859-860-861-862-863-864-865-866-867-868-869-870-871-872-873-874-875-876-877-878-879-880-881-882-883-884-885-886-887-888-889-890-891-892-893-894-895-896-897-898-899-900-901-902-903-904-905-906-907-908-909-910-911-912-913-914-915-916-917-918-919-920-921-922-923-924-925-926-927-928-929-930-931-932-933-934-935-936-937-938-939-940-941-942-943-944-945-946-947-948-949-950-951-952-953-954-955-956-957-958-959-960-961-962-963-964-965-966-967-968-969-970-971-972-973-974-975-976-977-978-979-980-981-982-983-984-985-986-987-988-989-990-991-992-993-994-995-996-997-998-999-1000 | 20 Jul 53 | 20,099.90 | FP | Packing Materials | Oct - Nov 53 | 20,099.90 | Complete |
| East Coast Aeronautics, Inc. | DA-30-069-CRD-177 | 25 Aug 53 | 219,383.51 | FP | Facilities | — | 219,383.51 | Complete |
| Whitin Machine Works | DA-19-020-CRD-3048 | 24 Dec 53 | 65,380.00 | CR | Facilities | Dec 53 - Apr 54 | 65,380.00 | Complete |
| Chaffee Brothers Co. | DA-1-28-017-501-502-503-504-505-506-507-508-509-510-511-512-513-514-515-516-517-518-519-520-521-522-523-524-525-526-527-528-529-530-531-532-533-534-535-536-537-538-539-540-541-542-543-544-545-546-547-548-549-550-551-552-553-554-555-556-557-558-559-560-561-562-563-564-565-566-567-568-569-570-571-572-573-574-575-576-577-578-579-580-581-582-583-584-585-586-587-588-589-590-591-592-593-594-595-596-597-598-599-600-601-602-603-604-605-606-607-608-609-610-611-612-613-614-615-616-617-618-619-620-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-636-637-638-639-640-641-642-643-644-645-646-647-648-649-650-651-652-653-654-655-656-657-658-659-660-661-662-663-664-665-666-667-668-669-670-671-672-673-674-675-676-677-678-679-680-681-682-683-684-685-686-687-688-689-690-691-692-693-694-695-696-697-698-699-700-701-702-703-704-705-706-707-708-709-710-711-712-713-714-715-716-717-718-719-720-721-722-723-724-725-726-727-728-729-730-731-732-733-734-735-736-737-738-739-740-741-742-743-744-745-746-747-748-749-750-751-752-753-754-755-756-757-758-759-760-761-762-763-764-765-766-767-768-769-770-771-772-773-774-775-776-777-778-779-780-781-782-783-784-785-786-787-788-789-790-791-792-793-794-795-796-797-798-799-800-801-802-803-804-805-806-807-808-809-810-811-812-813-814-815-816-817-818-819-820-821-822-823-824-825-826-827-828-829-830-831-832-833-834-835-836-837-838-839-840-841-842-843-844-845-846-847-848-849-850-851-852-853-854-855-856-857-858-859-860-861-862-863-864-865-866-867-868-869-870-871-872-873-874-875-876-877-878-879-880-881-882-883-884-885-886-887-888-889-890-891-892-893-894-895-896-897-898-899-900-901-902-903-904-905-906-907-908-909-910-911-912-913-914-915-916-917-918-919-920-921-922-923-924-925-926-927-928-929-930-931-932-933-934-935-936-937-938-939-940-941-942-943-944-945-946-947-948-949-950-951-952-953-954-955-956-957-958-959-960-961-962-963-964-965-966-967-968-969-970-971-972-973-974-975-976-977-978-979-980-981-982-983-984-985-986-987-988-989-990-991-992-993-994-995-996-997-998-999-1000 | 5 Aug 54 | 1,632.00 | C-E | Containers | Aug 54 | 1,632.80 | Complete |
| Philadelphia Ordnance District | 1954 Purchase Orders | — | 1,067.16 | FP | Miscellaneous Items | Stock Delivery | 1,067.16 | Complete |
| Boston Ordnance District | 1954 Purchase Orders | — | 3,181.32 | FP | Miscellaneous Items | Stock Delivery | 3,181.32 | Complete |
| New York Ordnance District | 1954 Purchase Orders | — | 6,744.30 | FP | Miscellaneous Items | Stock Delivery | 6,744.30 | Complete |
| Redstone Arsenal | 1954 Purchase Orders | — | 2,709.18 | FP | Miscellaneous Items | Stock Delivery | 2,709.18 | Complete |
| Redstone Arsenal | 1955 Purchase Orders | — | 1,614.99 | FP | Miscellaneous Items | Stock Delivery | 1,614.99 | Complete |
| Picatinny Arsenal | 1955 Purchase Orders | — | 1,661.40 | FP | Miscellaneous Items | Stock Delivery | 1,661.40 | Complete |
| TOTAL: | | | 12,845,980.37 | | | | 12,411,935.63 | |

FIGURE 2

CPFF - Cost Plus Fixed Fee
 FP - Fixed Price
 CR - Cost Reimbursable
 C-E - Open-End

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